RESEARCH AND DEVELOPMENT IN THE EARTH SCIENCES

FINAL REPORT

Prepared for the Canadian Geoscience Council

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FOREWORD

This study is designed to examine funding trends in research and development (R&D) in the earth sciences in Canada. The activities of federal and provincial governments, industry, and universities in earth sciences R&D are included. The relevance of earth-science-related R&D is considered in the light of the economic importance and probable future of the mineral sector, in order to evaluate current funding trends. Comparisons are made with the other academic disciplines and resource sectors in Canada, and with earth sciences and the mineral industry in seven other OECD countries. The OECD countries considered are Australia, Finland, France, the Federal Republic of Germany, Sweden, the United Kingdom and the United States. These countries have different approaches and attitudes towards R&D in general, and towards earth science R&D in particular, largely because the mineral sector plays differing roles in their economies. Comparisons with them will provide Canada with useful insights into its earth science R&D funding needs.

Where possible, the themes and conclusions are buttressed with statistics. However, it quickly became obvious in the course of this study that there were no easily derived data which encapsulated the various themes or allowed quick conclusions. A wide variety of data have been used, from published data sources as far as possible, and supplemented by interviews, on-site visits, and correspondence on a limited basis. Strong reservations must be noted about this fragmented data, and caution should be taken in its use as a guide for policy formulation. It is essential that the reader take into consideration:

- the reliability and consistency of published R&D data (which in many cases are questionable);
- the economic context, impact, and stage in the life cycle of the mineral industries studied, and the jurisdiction in which policy initiatives are being considered.

Simple statistical analysis and manipulation of R&D data will not provide easy answers to policy questions. Critical evaluation and judgement based on understanding are far more important inputs to the policy process. Data are merely raw materials. It is hoped that this study will provide reasonably reliable data for some of these raw material needs. It is also designed to provide some understanding of the relationships and dynamics involved in the economics, politics and technological evolution of the mineral sector, and the role of the earth sciences in this process.

The views expressed in this report and in the background studies are those of the author and not necessarily those of the Centre for Resource Studies and its sponsors, nor of the Canadian Geoscience Council.

Margot Wojciechowski
Centre for Resource Studies

ACKNOWLEDGEMENTS

The author would like to thank the Canadian Geoscience Council for initiating and funding this study, and the Canada Centre for Mineral and Energy Technology (CANMET) for funding a parallel study in mining and metallurgy. Doing the two studies in parallel has permitted synergistic benefits to accrue to both. Thanks are also extended to the many people who have been generous with their time and help in providing information and understanding in the course of research in Canada and in the seven OECD countries which have been surveyed. Partial lists of individuals who gave interviews and/or provided material are appended to the background studies. In addition, a number of individuals have read preliminary drafts of the study, in order to offer comments, corrections and advice. This assistance was essential in the preparation of the final report, and is greatly appreciated as well.

The untiring and wise assistance of Holly Lindsay, Nathalie Proulx, Kevin O'Grady and Tony Lemprière has been an essential part of the research and analysis for this study. The contribution of Dorothy Smith, Donna Stover, and Sandra Cantelon in keeping up with typing demands has been remarkable, particularly with the endless number of tables and the frequent exposure to Swedish, French, Finnish and German terminology. Anna Ortnas has been quick and creative in providing assistance with Swedish translations.

Although grateful for all the advice, information and help, the author accepts responsibility for the opinions expressed and conclusions reached.

Margot Wojciechowski
Centre for Resource Studies

Canadian Geoscience Council Preface

The Canadian Geoscience Council (CGC) is a forum of representatives of the thirteen major Canadian earth science societies, government agencies, and university departments, working cooperatively to encourage the development of the geosciences in the best interests of the nation, and of the geoscience professions. The Council provides advice to the federal and provincial governments on science policy and its implementation with respect to the earth sciences. It promotes science education in Canada, particularly for the earth sciences, and publishes periodic reviews and assessments of the status, health and activity of Canadian geoscience.

Since its inception in 1972 the Council has commissioned a number of studies covering various aspects of earth science related research. During 1985, it became apparent that data on funding of research and development in the earth sciences was inconsistent and unreliable and could not form an adequate base for decision-making in earth science policy. At the same time, major issues with a large geoscience component, such as global change and environmentally sustainable resource development, were coming to the forefront of society's concerns.

Thus, at the 56th meeting of the Canadian Geoscience Council in Toronto on March 13, 1986 the following motion was approved: "Moved D.K. Mustard, seconded I. Thomson: That the CGC initiate a study of comparative levels of geoscience funding in some developed countries, including Canada. That this study include examination of the comparative relationships between government expenditures and government revenues for geoscience and some other sectors of the economy..."

At the 57th meeting of Council in Quebec City, May 1986, it was agreed that the study would be an independent study contracted to the Centre for Resource Studies at Queen's University. A committee of the Geoscience Council was formed to prepare terms of reference for the study. Members were: D.K. Mustard, Canadian Geoscience Council; A. Beck, Council of Chairmen of Canadian Earth Science Departments; D. Devanny, Canadian Geotechnical Society; C. Jennings, Geological Association of Canada; W.A. Padgham, Committee of Provincial Geologists; and R. Riddihough, Geological Survey of Canada. The committee met with representatives from the National Science and Engineering Research Council (N. Lloyd); Energy, Mines and Resources (R. Price); and the Centre for Resource Studies at Queen's University (M. Wojciechowski) at the offices of the Mining Association of Canada in Ottawa on 29 July 1986 and approved the Terms of Reference for the study.

Funding for the study was provided equally by (1) provincial governments, (2) federal agencies and (3) the private sector.

The concept of the study was introduced as a brief to the Mines Ministers' Conference at Banff, Alberta, in September 1986. Financial support for the study was received from the Provinces of Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland,

Nova Scotia, Ontario, Quebec and Saskatchewan. The Ministers of Mines and their staffs are to be thanked for their generous contributions.

The federal government's share of funding derived entirely from Energy, Mines and Resources Canada, and thanks are due to The Honourable Gerald Merrithew, Minister of State for Mines, to P. Perron, Associate Deputy Minister of EMR, and to R. Price, Assistant Deputy Minister, Geological Survey of Canada Sector, for their continuing support.

A major contribution was received from the Canadian Petroleum Association on behalf of the oil and gas industry and special thanks are due to I. Smyth and G. Henderson for their efforts. Contributions from individual resource companies came from BP Resources Canada Limited, Dome Mines Limited, Esso Resources, Rio Algom Limited and Falconbridge Limited, and are gratefully acknowledged.

Finally, Charles Camsell Society in Yellowknife made a generous donation and thanks are due to the British Columbia and Yukon Chamber of Mines for support services during fund raising.

Views and conclusions included within the report are those of the author of the report, Margot Wojciechowski, and do not necessarily reflect those of the Canadian Geoscience Council or the funding organizations. The data derived from the study and contained within the report and in the background documents are a uniquely complete compilation of information that was previously unreported, unrecorded or lost in broad statistical compilations. The study is a significant contribution to our appreciation of the status of a sector of Canadian activity that will become increasingly important to the nation in the decades ahead.

D.K. Mustard
Canadian Geoscience Council

Avant-Propos du Conseil Géoscientifique Canadien

Le Conseil Géoscientifique Canadien regroupe et représente treize des sociétés importantes canadiennes en sciences de la terre, les agences gouvernementales et les départements des sciences de la terre des universités dans un effort coopératif, ceci afin de développer les sciences dans le meilleur intérêt pour le pays ainsi que pour les professions impliqueés. Le Conseil offre des avis aux gouvernements fédéral et provinciaux en ce qui concernent les politiques touchant les sciences de la terre. Il encourage, également, l'éducation scientifique au Canada, plus particulièrement en sciences de la terre, et il publie périodiquement des études visant le statut, l'état, et les activités des domaines géoscientifiques canadiens.

Depuis ses débuts en 1972, le Conseil a fait effectué de nombreuses études touchant les divers aspects de la recherche en sciences de la terre. Pendant l'année 1985, il est apparu que les données traitantes le niveau de financement de la recherche géoscientifique étaient contradictoires, incertaines, et qu'elles ne pouvaient pas servir de base adéquate pour la formulation des politiques en matière géoscientifique. Pendant cette même époque, des thèmes importants touchant plusieurs aspects des sciences de la terre, comme les changements globaux, et le développement des resources sur une base soutenue tenant compte de l'environnement, occupaient de plus en plus les attentions de nos sociétés-membres.

Dans de telles circonstances, à la 56e réunion du Conseil géoscientifique canadien, tenue à Toronto le 13 mars, 1986, la proposition suivante a été acceptée. "Proposée par D.K. Mustard, secondée par I. Thomson: que le Conseil géoscientifique canadien amorce une étude ayant pour but de comparer le niveau de financement en sciences de la terre dans plusieurs pays industrialisés, incluant le Canada. Que cette étude comprenne l'examen des rapports comparatifs entre les dépenses et les revenues gouvernementaux touchant le secteur géoscientifique ainsi que d'autres secteurs de l'économie..."

A la 57e réunion du Conseil, tenue à Québec en mai, 1986, il fut accepté que l'étude serait indépendante et donnée sous contrat au centre des études sur les ressources de l'université Queen's. Un comité a été formé afin de préparer les termes de référence propre à l'étude. Les membres du comité étaient D.K. Mustard, Conseil géoscientifique canadien; A. Beck, Conseil des Directeurs des Départements des Sciences de la Terre; D. Devanny, Société canadienne de géotechnique; C. Jennings, Association égologique du Canada; W.A. Padgham, Comité des Géologues provinciaux, et R. Riddihough, Commission géologique du Canada. Le comité a rencontré des représentants du Conseil de recherches en sciences naturelles et en génie du Canada (N. Lloyd); Energie, Mines et Ressources Canada (R. Price); et le Centre pour Etudes des Ressources à l'Université Queen's (M. Wojciechowski) au bureau de l'Association des Mines du Canada, Ottawa le 29 juillet, 1986 et a donné son acceptation aux termes de référence relatives à l'étude.

L'étude a été financée à part égale par (1) des gouvernements provinciaux, (2) des agences fédérales, et (3) le secteur privé.

Le concept de cette étude fut présenté dans un dossier à la conférence des ministres des mines à Banff, Alberta, en septembre, 1986. L'étude a reçu l'appui financier des provinces de Alberta, la Columbie Britannique, Manitoba, Nouveau-Brunswick, Nouvelle-Ecosse, Ontario, Québec, Saskatchewan, et Terre-Neuve. Nous remercions les ministres des mines et leur personnel de leur contributions généreuses.

La portion du financement du Gouvernement Fédéral provenait entièrement du Département de l'Energie, Mines et Ressources, Canada, et nous remercions l'Honorable Gerald Merrithew, Ministre d'Etat pour Mines, P. Perron, sous-ministre associé, EMR, ainsi que R. Price, sous-ministre adjoint, Secteur de la Commission Géologique du Canada pour leur appui continu.

Une contribution importante a été reçue de l'Assocation canadienne du pétrole, representant l'industrie pétrolière, et des remerciements spéciaux reviennent à I. Smyth et G. Henderson en hommage à leurs efforts. Nous reconnaissons avec gratitude la contribution des compagnies des ressources suivantes: BP Resources Canada, Dome Mines Limited, ESSO Resources, Rio Algom Limited, et Falconbridge Limited.

Egalement, la Charles Camsell Society de Yellowknife a offert un don généreux, et nous remercions The British Columbia and Yukon Chamber of Mines de leur soutien pendant nos activités relatives à la recherche de financement.

Les avis ainsi que les conclusions compris dans ce rapport sont ceux de l'auteur, Margot Wojciechowski, et ne sont pas nécessairement ceux du Conseil canadien géoscientifique ni des organismes qui ont fourni le financement de l'étude. Les données qui en découlent, et qui font partie de ce rapport, ainsi que celles qui paraissent dans la documentation d'appui forment une compilation complète des informations antérieurement non disponibles; soient non-signalées, non-compilées, soient perdues dans de large études statistiques. Cette étude amène un apport significatif à notre compréhension du statut de ce secteur d'activité canadien, secteur qui deviendra de plus en plus important au pays dans les années à venir.

D.K. Mustard
Conseil géoscientifique canadien.

SUMMARY OF FINDINGS

Canada has a good mineral endowment, good economic mineral potential, and good long-term prospects for a strong mineral producing sector across many regions and many commodities. To realize this potential, Canada's mineral industry must find and produce its commodities, processed to whatever degree that markets allow, at costs that are competitive. Since a growing portion of Canada's competition comes from countries that are at an earlier stage in their mineral industries' life cycle, Canada's comparative advantage must be found not necessarily in the lowest-cost highest-grade deposits but in the best technology for finding, producing and processing minerals.

R&D in the earth sciences, geosciences, and exploration-related technology, as well as innovation in theories, techniques and equipment, are all essential to the development and maintenance of technological leadership in finding economic mineral deposits. It appears that Canada is well placed to perform this R&D, and to realize its comparative advantages. Canada has geological survey organizations that are second to none in the world to provide it with a geoscience data base and contribute to R&D in the earth sciences. There are many strong university departments of Earth Science and of Geology for basic and applied research, and for training future generations of experts. There is a strong industry exploration sector, and excellent capabilities in geophysical and other geoscience instrumentation and techniques.

Additional advantages would seem to accrue to Canada from the fact that many of the countries that have been leaders in mineral production and in related technologies are nearing the end of their mineral industries' life cycle. New competition is developing, but mainly in countries which do not have Canada's advantages of established earth science and geoscience organizations and education programs.

The logical Canadian response would seem to be a concerted effort in R&D and innovation, to fill the gap being opened up by the decline of traditional producers, and to stay ahead of the new producers in technological leadership. However, this study does not find evidence of such a response. Government and industry R&D policies and programs in Canada seem to be following the pattern of countries where the mineral sector is in decline, rather than seizing the opportunities presented.

Government extramural R&D funding programs in general are shifting towards applied research, largely within a university funding framework designed for basic research; meanwhile, little attention is being given to developing the essential links between university R&D and the needs of the industrial sector. Governments' R&D focus is shifting away from

resources, where Canada has a comparative advantage, and towards downstream manufacturing and high technology, where experience has shown that Canada does not. The funding base of the Geological Survey of Canada and of some of the provincial surveys has been eroded. This trend has been disguised by the introduction of temporary funding programs with no long-term guarantees.

University R&D funding and graduate student enrollment in the earth sciences have grown, but have not kept pace with the growth in other natural science and engineeering disciplines.

The picture looks even bleaker in the private sector. Exploration expenditures are more closely tied to world prices for the mineral commodities being sought than to the industry's need for replacement of reserves. One result is a growing concern over a lack of base metal reserves. Another is the far-reaching hardships caused by volatility in the oil and gas exploration sector. Mining and exploration company expenditures on earth science and exploration R&D are extremely low. Only a very small group of instrumentation companies show R&D expenditures at a level sufficient to support an effective innovation effort.

These conclusions are in many cases derived intuitively, since data simply do not exist to support them. For example, published statistics cannot tell us that Canada has geological survey organizations and an exploration industry sector that are second to none in the world. They do show a decline in the base funding of the Geological Survey of Canada and in some of the provincial surveys. Data series based on the 1980-1985 period tell us something about past experience, but they do not reveal that Canada has good long-term potential for new economic mineral discoveries. The data do show exploration expenditures that respond mainly to short-term mineral price flucuations. While Canada's pre-eminence in the development, manufacture and use of geophysical instrumentation is well known, data on these activities are statistically buried in several categories of industrial classifications.

Historical data series without interpretation cannot tell us that Canada's mineral industry has the potential to make an important contribution to Canada's economy and export trade for a long time to come. Instead, they show declines in the relative economic importance of the industry in almost every category of measurement. Simple extrapolation suggests that the declines will continue. In fact, however, they reflect structural readjustment in response to supply and demand shifts and to the inevitable long-term decline of prices for resource commodities relative to prices as a whole. (See appendix table B3.) The

industry will stabilize at new plateaus, which may be lower for some commodities in terms of relative impact in the economy, but which will be viable and vigorous for the long term.

In spite of data shortcomings, this report and the background studies on which it is based provide strong support for the basic conclusion of the study: Canada has good economic justification for maintaining and increasing its expenditure levels in earth science R&D. Unfortunately, R&D expenditure levels are losing ground in the public sector, and they are extremely low and probably declining as well in the private sector.

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CHAPTER 1. INTRODUCTION

PURPOSE OF THE STUDY

This study was undertaken for the Canadian Geoscience Council and attempts to create an understanding of earth science research and development funding trends and the relationship of the earth sciences to the mineral sector. This task involved:

- providing information on trends in the level, sources and focus of research and development (R&D) funding of the earth sciences in Canada;

- setting this information in context by providing information on the role of the earth sciences in the mineral and petroleum industries, and on the role of these industries in the Canadian economy;

- providing information on trends in education in the earth sciences in Canada;

- comparing the trends shown for earth sciences in Canada with those of other disciplines;

- comparing the mineral sector and its earth science R&D with other resource sectors in Canada;

- comparing the above information with similar data on earth science R&D activity in seven OECD countries: Australia, Finland, France, the Federal Republic of Germany, Sweden, the United Kingdom and the United States;

- considering the data on levels and trends in earth science R&D activity in light of the current and future needs of the mineral sector and in relation to how other sectors and countries have dealt with a changing economic climate and industrial structure.

DEFINITIONS AND SCOPE OF THE STUDY

The earth sciences for the purpose of this study comprise geology and geophysics, including all their subdisciplines such as palaeontology and seismology, physical geography, remote sensing, climatology, physical oceanography and chemical oceanography. The disciplines correspond for the most part to the disciplines covered by the Earth Science Grant Selection Committee of the Natural Sciences and Engineering Council of Canada (NSERC), codes 3300 - 3390, and to the list of the solid-earth science disciplines given in a earth science background study conducted for the Science Council of Canada in 1971.[1]

This study will also look at some aspects of R&D funding for geotechnics, and rock mechanics, which fall under the Civil Engineering Grant Selection Committee of NSERC. Hydrological studies of specific watersheds, which are conducted by investigators both in civil engineering and in geography departments, mostly fall under the Civil Engineering Committee.

The mineral or mining industry for the purpose of this study includes: exploration for and primary production of metallic concentrates, metals, non-metallic minerals including structural materials, and coal.

The **petroleum industry** for the purpose of this study includes: exploration for and production of crude oil and natural gas. It does not include refining or production of petrochemicals or derived products. Occasionally, "mineral industry" is also used as a collective to include both the mining and the petroleum sectors.

Crude minerals are metallic ores and concentrates, unprocessed nonmetallic mineral commodities (i.e. the products of the mining industry), plus crude petroleum and natural gas.

Expenditures on the compilation of **geoscience data bases** are included in this study, but shown separately from R&D, as government geological survey activities.

Exploration and prospecting are not considered to be R&D activities (see R&D below), but are also included in this study, as part of the economic context of the mineral sector.

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1. Science Council of Canada, Earth Sciences Serving the Nation, Special Study No. 13, (Ottawa: 1971).

Research and Development (R&D) for the purpose of this study is considered to include: contributions to the basic theoretical framework of the earth sciences; novel applications of earth science data; syntheses, involving, for example, tectonic interpretations of large-scale geophysical data; and the development of new instrument systems or software for collecting, interpreting or transmitting data.

To facilitate international comparisons, this study attempts to conform as closely as possible to the OECD definition of R&D in earth sciences. The Frascati manual published by the OECD[2] notes that there are problems in distinguishing research activities in the earth sciences from scientific and technological services. This is particularly true in government geoscience and survey agencies such as the Geological Survey of Canada and the corresponding provincial surveys. According to the Frascati Manual, only the following activities should be considered as R&D per se:

- development of new or substantially improved methods, and equipment for data acquisition and for the processing and study of the data collected and for the interpretation of these data;
- surveying done as an integral part of an R&D project on geological phenomena undertaken for primarily scientific purposes.

It appears that for the most part the foreign countries examined as part of this study adhere to the OECD framework for classification of R&D. Statistics Canada also uses the OECD definitions in its R&D surveys and data series. In its publication on R&D measurement, Statistics Canada quotes the OECD (and UNESCO) definition of R&D as "creative work undertaken on a systematic basis in order to increase the stock of knowledge."[3] The basic criterion for distinguishing R&D from the rest of scientific and technological activity is that there be an "appreciable element of novelty".

In its data series, Statistics Canada distinguishes between R&D, as described here, and **related scientific activities** (RSA) which complement and extend R&D by the generation, dissemination, and application of scientific and technological knowledge. R&D and RSA together comprise the **science and technology** (S&T) category in the data series. Among the RSA items reported by Statistics Canada are scientific data collection and information services, which constitute the bulk of the activities of federal and provincial geological surveys and other geoscience programs.

2. OECD, The Measurement of Scientific and Technical Activities; proposed standard practice for surveys of research and experimental development, "Frascati Manual" 1980, (Paris: 1981).
3. Statistics Canada, A Framework for Measuring Research and Development Expenditures in Canada, 88-506E, March 1984.

For those who wish to include geoscience data collection or mineral exploration in their own definition of R&D, the numbers are available here, although identifed separately for the purposes of this study.

Various measures of **R&D intensity** are possible, including R&D as a percent of value added or of GDP value, and R&D as a percent of value of production or sales revenue. The former measure is preferable, since it relates R&D effort more closely to each sector's real economic contribution. However, in many instances, the second measure of value is the only one possible, given the available R&D data and economic data by industrial category.

There are a number of commonly used **aggregate measures of R&D** effort. Gross expenditures on R&D (GERD) includes expenditures from all sectors including governments, business, institutions of higher education, other organizations and foreign sources. The composition of GERD can be examined in terms of who provides the funds or who performs the R&D activity. A frequently used statistic is business expenditures on R&D (BERD), which also may have either a funding or a performing perspective.

A country is described as **export dependent** for a certain commodity or sector when domestic production of the commodity or in the sector exceeds domestic requirements, and therefore current production levels depend on export markets for sales. The commodity or sector may also play a significant role in the trade balance, depending on the proportion of total exports it represents.

Import dependence refers to a situation where domestic production of a commodity or sector does not meet domestic requirements, whether for consumption or for processing and re-export.

The **time period** covered by this study is generally from 1980 to 1987. This time period is very short for observing and analyzing economic trends, particularly for a sector such as mining where lead times are so long. It is also not a typical period for the mineral sector, with a strong beginning followed by deterioration of demand and prices for most commodities. However, it has been dictated by the availability of data, particularly for R&D expenditures. In some cases even less data is available, while in others longer series can be assembled. As much data as possible has been assembled and is provided in the background studies. For consistency, a 1980-85 timeframe is generally used in this summary and synthesis volume. This reduces the timeliness of the data, but was dictated by data availability.

The **currency units** used in chapter 3 to describe the Canadian mineral industry are constant 1981 Canadian dollars. Percent change is real change, based on 1981 dollars. For international comparisons in the tables in chapters 4, 5 and 6, 1985 US dollars have been used. Percent change again is real, based on real domestic currency values. Appendix B contains the exchange rates that were used for currency conversion.

DATA SOURCES AND USE

The principal data sources for Canada are published data prepared by Statistics Canada and by the Department of Energy, Mines and Resources. In some cases, special tabulations of unpublished material have been received from these organizations as well. These sources are by far the most detailed and reliable of any available. The major drawbacks to their use are the time lags in some of the data series, lack of disaggregation, and the confidentiality requirements which prevent detailed breakdowns of some types of information.

For the foreign studies, important published data sources included studies released by the OECD and other international organizations, government statistical agencies, and other government agencies including Geological Survey organizations and the appropriate Ministries responsible for the mining and energy industries. A wide variety of additional published sources were used for qualitative and quantitative information, including government reports and publications, earth sciences journals and bulletins, and university and company reports.

Beyond these readily available published sources, CRS has sought additional data by a number of methods. For Canada, original data were derived in four major ways: a survey of provincial government expenditures on geoscience activities; a survey of university activities related to earth sciences; a special compilation from NSERC on its support for earth science R&D; and a survey of R&D activities of consulting, contracting, and equipment manufacturing firms in the geoscience field. While the detail of primary data makes them attractive, the lack of uniformity, and in some cases the low survey response rate, are negative factors.

For the foreign country studies, the published data sources were supplemented by interviews and correspondence with industry, government, university and other representatives in each of the seven other OECD countries examined. These proved to be very useful, since they provided a good qualitative sense of R&D activity and of the role and future of the mineral sector, which might have been obscured by examining statistics alone. They also provided access to additional data sources. Lists of interviews and correspondents are appended to the individual background studies.

In the course of collecting the background information and data for this study over the past 2 years, it has become apparent that the R&D statistics, like most statistics and probably more than most, can be very misleading. When examining the data presented in this study a number of factors should be kept in mind. First, the R&D expenditure data series that are widely available and comparable in methodology are relatively short (roughly 1980 to 1986) for establishing trends; they are not

reliable, and they are in fact still not very comparable in terms of quality, definitions and degree of disaggregation. Reported R&D expenditures differ between countries according to systems of reporting, tax law, and government incentive programs.

Second, in order to make sense of the R&D expenditure data that are available, it is necessary to set them into the overall context of the economic role of mining in each country. Unfortunately, the period 1980-86 for which data are available is hardly a typical one for evaluation of long-term trends in the mineral sector.

Third, and most important, the R&D practices of other producers, however successful, cannot be transferred directly to Canada and expected to work here. They must be examined in the light of the needs they were designed to meet, and the economic, political and social factors that shaped them. Their relevance must then be assessed in the light of Canada's needs and special characteristics. Only then can the lessons learned be applied to remedy our weaknesses and build on our strengths.

ORGANIZATION OF THE STUDY

This report represents a summary and synthesis of a vast amount of material on the mineral sector and earth-science-related R&D activity. Eight background studies provide the basis for this study: these are seven reviews of R&D policy and earth science R&D in the OECD countries used for comparison purposes, and a detailed examination of the situation in Canada. These background reports are, for the most part, presentations of data and some analysis, but with little or no comparative treatment. The comparative analysis and assessment are provided in this volume. Readers are referred to the background studies for a more detailed look at the individual countries.

Chapter 2 of this study defines a four-part framework for the analysis and comparison of R&D needs and policy responses, and of the effectiveness and appropriateness of these reponses.

Chapter 3 provides a summary of the background study on Canadian earth sciences R&D and the mining and oil and gas industries. A review of the role of these sectors in the Canadian economy is followed by an examination of federal, provincial and industrial support for earth sciences data-gathering and R&D activities. Trends in education in the earth sciences and in general are compared. Brief comparisons of R&D funding levels and other relevant factors for scientific and technical disciplines other than earth sciences, and for resource sectors other than the mineral industry, are provided.

Chapter 4 begins the analysis of R&D effort in the earth sciences with a discussion of the economic context, as illustrated by the first two factors in the framework. Canada's mineral industry is placed in the mature phase of its life-cycle, and its import/export dependency is examined. Brief comparisons with the mineral industries in other countries are made, to provide a setting for analyzing R&D needs and policy actions.

Chapter 5 continues the analysis with a look at the last two factors in the framework: socio-economic policies including R&D activities, and the cultural factor.

Chapter 6 contains a comparison of earth science R&D in Canada with that in the seven other OECD countries considered. R&D levels and trends are examined in the light of the discussion in chapters 4 and 5, to see what lessons can be learned about future directions for earth sciences R&D activity in Canada.

Chapter 7 concludes the study with recommendations for action by governments, industry and universities.

One-page summaries of the international background studies are presented in the first appendix.

CHAPTER 2. A FRAMEWORK FOR THE ANALYSIS OF R&D ACTIVITY

There are many possible approaches and levels of analysis in evaluating R&D policies and funding programs. This chapter outlines the approach of this study for using the data constructively, and for deriving lessons that Canadian governments and the mineral industry can learn from experiences in other places and other times. Much may already be intuitively obvious; however, few people have the luxury of time for the sort of systematic data collection and comparative analysis that is necessary to back intuition with supporting arguments. It is useful to create a simple framework for observation and analysis (see the schematic in figure 2.1), by identifying four factors within each country that are particularly important determinants of the R&D needs of the mineral industry, of the policy responses triggered by those needs, and of the effectiveness of the responses. The four factors are:

1. the stages in the mineral industry life cycle;
2. import/export dependency;
3. the socio/political environment;
4. the cultural factor.

The first two factors are dominant in determining the mineral industry's needs, and influence the responses as well; they are dynamic and they are interdependent. For example, for a mineral-exporting country, the winding down of the life cycle of a commodity or a branch of mineral production means falling exports, and possible eventual import dependency. They are also clearly measurable in quantitative terms. The third factor, a collection of social and political goals and policies that is unique to each country, shapes the R&D responses to the industry's needs, and affects the focus of the effort and the level and sources of R&D funding. It is more qualitative and elusive than the first two, but not impossible to describe usefully. The fourth, the cultural factor, is one of attitudes, and is an often-unrecognized but crucial determinant of the effectiveness of the R&D responses. In some of its manifestations, such as percent of engineers in various sectors and levels of R&D and management, it can be measured. In general, however, it must be described qualitatively, and in terms of degrees, rather than absolutes.

Looking at past, present, and future mineral producing countries in the light of these four factors, it is possible to see patterns of behavior that can assist policy makers in reaching conclusions about the necessary future direction for earth sciences R&D in Canada.

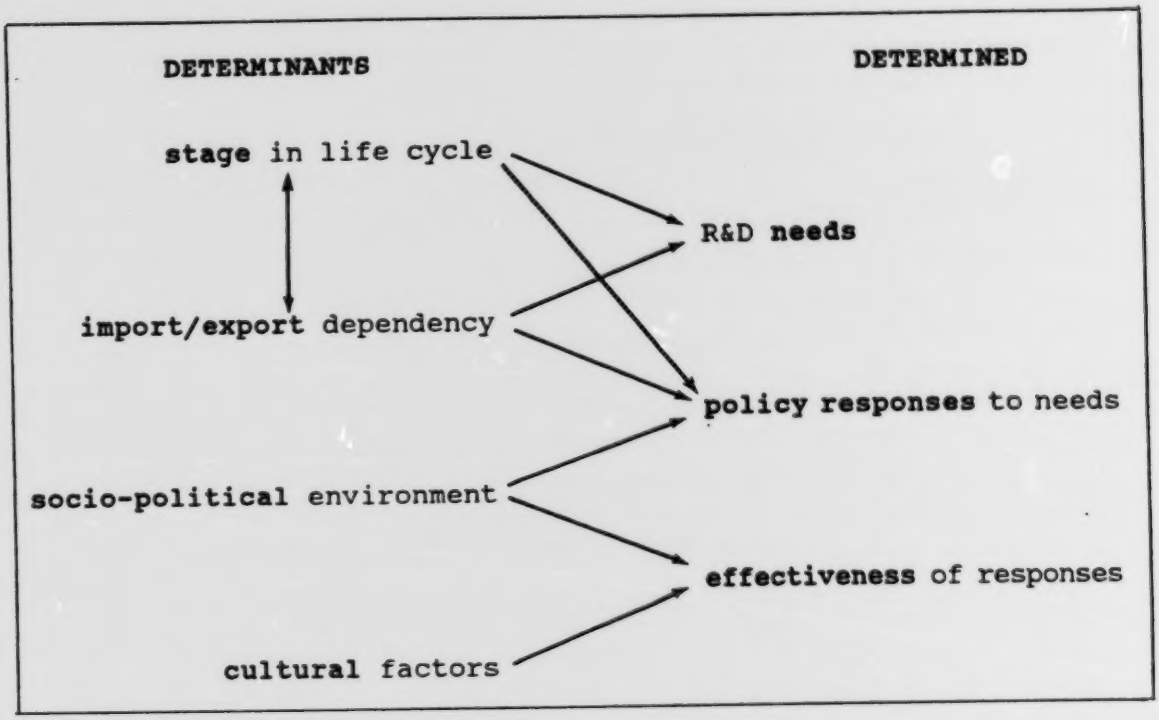

Figure 2.1 A Framework For the Analysis of Research And Development.

THE FRAMEWORK

1. Stages in the Mineral Industry Life Cycle

The mineral industry life cycle, for a single commodity or a range of commodities, follows a more-or-less continuous curve. Nevertheless, it is possible to divide the curve into sections over time. Four divisions are suggested here, arbitrary divisions that provide a useful basis for observation and for comparison: the initial stage, the early years of growth, maturity, and decline.

The Initial Stage

This stage is now evident in the establishment of mineral production capability, principally for export, in a number of less developed countries that are frequently identified as threats or potential threats to Canadian mineral export markets because of their low-cost high-grade deposits. It usually involves rapid growth of production and of exports of primary materials. The stage is generally characterized by dependence on imported technology and expertise to find the minerals and bring the deposits into production. Once a cash flow is generated, little of it is directed at reinvestment in R&D. Rather, it goes principally for debt repayment and for social and political priorities in other areas. Nor is there much domestic capability for R&D or geoscience activities in the initial stage, since it takes time for a country to build up an infrastructure of skilled human resources, educational facilities, and scientific and professional organizations.

Growth Stage

The second stage is generally one of less dramatic but continuing growth and of building up of domestic resources to replace foreign technology and skills. Development of domestic capabilities is not inevitable; some countries, particularly newly independent ones with a host of other overwhelming problems, do not seem to achieve much success in this. Others - and India, Brazil, China and other Pacific nations come to mind - initiate R&D efforts focused on productivity improvements, expansion of production, and expansion of markets for production in excess of domestic requirements. They establish university programs, R&D facilities, geoscience and exploration expertise, and related equipment manufacturing capability. Many have the assistance of national and international aid programs in these tasks. Deposits continue to be low-cost and high-grade because depletion effects have not yet been felt.

Unfortunately, none of the countries included in this study are in the first two stages of growth. Their addition would provide useful information to Canadian policy makers and R&D managers, since they are a growing source of competition, both in mineral production and in mineral technology. However, dependable economic and R&D data are not available in sufficient detail for these countries to allow reliable conclusions to be made.

Third Stage - Maturity

This is a stage of relative stability, with long-term slow growth potential. The term maturity is meant to connote full development rather than imminent decline. Depletion effects are countered by technological innovation. The length of time a country's mineral industry, or a branch of it, spends in this phase depends on:

- the size and quality of the mineral endowment;
- the effectiveness of geoscience data collection and earth science R&D;
- the quality of exploration and production technology;
- the rate of exploitation;
- and, on the demand side, markets and prices.

For major producers such as Canada and Australia, this stage can span decades, or even centuries. The mature industry's R&D needs are much more diverse and less clearly defined than in the earlier stages of rapid growth and expansion of market share. In addition to production and productivity, the goals of R&D expand to include health, safety and environmental protection, improvements in product quality, and the development of new products. The goals should also include long-term basic R&D aimed at improved understanding of the resource potential and at improved exploration technology and techniques, to maintain competitive position in the face of depletion of more accessible higher grade and lower cost deposits.

Because this stage is long term and slow in growth, it is vulnerable to erosion by short-term mineral supply and demand cycles that overlap the long-term trend lines. As a result, the R&D and exploration needs may go relatively unrecognized, hampered by cuts in funding in hard times, and worse, by complacency in good times. The maturity stage demands strong and unwavering commitment to R&D and exploration activities, and continuing improvement of the geoscience data base, to ensure continuing mineral supplies, innovation and competitive strength.

Decline

There is no sharp demarcation between maturity and decline, and sometimes no certain way of distinguishing between a downturn during maturity and an irreversible decline. Old age does not necessarily indicate decline. As long as there are economic deposits and reserves, good geological potential, and markets for the output, competitive position can be maintained. Nevertheless, for all producers, depletion will eventually lead to decline, at least until the world's easily developed deposits have been exploited and new generations of exploration technology and earth science knowledge bring new generations of deposits on stream. All the countries in this study except Australia and Canada are either approaching or in the decline phase in primary mineral production for most metallic minerals.

In decline (as in downturns during maturity), initial reactions tend to include an increase of industry initiatives such as exploration activities and R&D aimed at cost-cutting and productivity improvement, and of government initiatives such as incentives or subsidies for exploration and development, and short-term community and labor force assistance. Sometimes the two public policy thrusts come into conflict, as is now the case in the UK, France and Germany, where rationalization of the coal and steel industries to cut costs exacerbates the job losses in these sectors.

Exploration assistance on the other hand has the opposite effect, since it results in increased employment, at least in the short term. In the case of genuine permanent decline, the social assistance focus shifts to economic diversification. The exploration subsidies will be dropped if no potential is seen, as has happened in UK, Sweden, Germany and Finland; they may be directed offshore if import dependency is considered to be a potential problem, as happened for many years in France and Germany and briefly in Finland. Eventually, exploration and production R&D programs will decline, and the emphasis turns to materials conservation, substitution, and higher-value-added activities, as has happened in all of the European countries in the study.

2. Import/Export Dependence

This second key variable shows a wide range among the countries included in this study, and within commodity categories. Finland and Sweden, for example, import all their energy minerals and are increasingly dependent on imports of metallic minerals for the production of fabricated metal products (much of which they export). England has long since depleted most of its known economic metallic mineral deposits, and has had a brief

reprieve in energy minerals. The United States, like Europe, is increasingly dependent on imports of almost all mineral commodities to meet its domestic demand. Canada and Australia, on the other hand, produce a broad range of energy, metallic, and nonmetallic minerals in excess of domestic requirements, and depend on export markets for these materials, mainly in unprocessed form.

Export dependency, like the growth stage of mineral production, should lead to an R&D focus on productivity improvements in all phases of discovery and production up to the stage at which commodities are exported, in order to maintain competitive position and market share. Although primary mineral commodities are generally competitive only in terms of price, and not because of product differentiation, primary mineral exporters may also be able to increase their export potential through R&D in new product development and new applications. Unfortunately, it is more difficult to capture the benefits of R&D in these higher-value-added activities since the advantage of access to low-cost raw materials loses its importance relative to other factors such as speed of implementation and marketing skills.

Import dependency on the other hand, whether for domestically consumed goods or for materials used in the production of goods for export, leads to strong pressures for R&D programs focusing on efficiency in the use of raw materials and on substitution away from imported materials. It may also lead to geoscience activities aimed at understanding the geology and mineral potential of the country, and to mineral exploration programs, either domestic or offshore. The degree to which security of supply is a national priority will affect the nature and intensity of the responses.

3. The Socio-Political Environment

Economic conditions are of key importance in determining total R&D funding levels and focus in each country, particularly the level of defence spending, the relative importance of resources and manufacturing, and the concentration and ownership of the industry. In addition, there are many economic, social and political influences that specifically affect mineral policies and R&D responses, including fiscal and monetary policies (and exchange rates), concerns over security of materials and/or energy supply, quality of education, environmental protection, health and safety, attitudes towards foreign and state ownership, trade policies and access to trading blocs, and many more. Some are unique to individual countries, and some are found everywhere. A dominant goal in most of the countries

studied is job creation, which in Canada and elsewhere is part and parcel of regional economic development and a driving force in resource policies. In Finland, regional development needs have led to an emphasis on northern regions in the program of the Geological Survey.

A striking example of the effect of the pressure for job creation is found in the high-cost European coal industry, which, in one sense, does not mine coal at all: it mines jobs. European producers could buy coal elsewhere more cheaply, but they prefer to subsidize production in order to maintain employment and support communities and entire regions. The R&D focus in some cases implicitly recognizes this fact by virtually ignoring the major problem in coal production, high labor costs, since solving it would lead to massive layoffs.

Social and political forces rarely give rise to R&D programs that have scientific excellence, cost-cutting, or productivity gains as their principal focus. In some cases the R&D may increase the direct costs of production, although it reduces social costs or offers other benefits. Government-mandated R&D programs, for example for environmental protection or worker health and safety, generally grow in significance throughout the maturity stage of the industry. Other government policies and programs may also impose costs. Exploration incentive programs may promote activities in high-cost regions. Further processing requirements add costs, if alternative processing facilities are already available. These socially and politically-motivated programs are very difficult to design and to evaluate, because there is often no direct measurable economic link between the costs of the programs and the resulting benefits, and little integration of technological expertise into the program design at the policy level.

4. The Cultural Factor

The fourth critical factor, one that shapes the effectiveness of each country's R&D effort, is cultural; it arises from the attitudes towards and utilization of science and technology within each country. Consider, for example, the spectrum of attitudes represented by C.P. Snow's "Two Cultures", with relative isolation of and lack of esteem for scientists and engineers at one end of the scale, and the integration of technology and management in Japanese industry and government at the other. Lester Thurow finds that the two-cultures attitude is "peculiar to the Anglo-Saxon world",[1] and leads to biases that handicap both education and industry. The two-cultures attitude leads to poorer education in the

1. Lester Thurow, "A Weakness in Process Technology", Science, 18, December 1987.

sciences, with split streams for sciences and non-science subjects, and virtually no exposure to science and technology for those in the non-science stream.

This attitude seems to be noticeably stronger in Britain than in Canada and probably stronger in Canada than the United States and Australia, but is a handicap in all four. Compared to Japan and Germany, Thurow argues, fewer students, and a smaller proportion of top students, enter the science stream in the United States because it is not seen as a career path to senior positions, and fewer students enter graduate courses in engineering for the same reason. The attitude also leads to fewer technically-trained production managers and senior executives, lower priority for R&D and for workforce upgrading, and resistance to process innovation and to investments that do not offer immediate returns. In other words, insufficient technical input into the policy process can and does lead to ineffective R&D programs. Furthermore, even with an outstanding R&D performance and a good level of R&D funding, lack of integration of science and technology into production can prevent the R&D successes from being translated into commercial successes.

CHAPTER 3. THE EARTH SCIENCES AND THE CRUDE MINERAL SECTOR IN CANADA: A Summary of the Canada Earth Sciences Background Study[1]

INTRODUCTION

This chapter summarizes the Canadian background study, in order to provide information on Canadian expenditure levels and trends in:

- geoscience data collection by federal and provincial governments;
- R&D intramural activities of government;
- R&D extramural support by government in earth sciences;
- industry exploration activities;
- industry R&D activities;
- education in earth sciences;
- comparisons with other disciplines and other resource sectors.

The geoscience data collection and mineral exploration data are kept separate from the R&D expenditure data, but reinforce the R&D information and help to put it into the context of government and industry interest in the area of earth science. First, information on the economic impact of the crude minerals industry in Canada is presented.

THE MINING AND OIL AND GAS SECTORS: An Economic Measure of the Contribution of Earth Sciences in Canada

In order to understand the economic importance of the earth sciences in Canada, it helps to examine the role of the crude mineral sector in the Canadian economy. It is also important to remember that the economic contributions and commercial applications of the earth sciences reach far beyond the mineral industry. The earth sciences are of relevance in, for example, civil engineering, transportation, defence, water resources, energy, agriculture and Arctic activities. Earth-science-related activities also provide a fundamental understanding of the earth, its origins and nature. In evaluating the contribution of the earth sciences for policy purposes it is important to consider these aspects, in addition to the direct economic links to the mineral industry discussed here.

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1. Margot Wojciechowski, "R&D Funding Trends in Earth Sciences in Canada", Background Study to Final Report, Research and Development in Earth Sciences, prepared for Canadian Geoscience Council by Centre for Resource Studies, Kingston, December 1988.

Five key characteristics of the crude mineral industry in Canada in the 1980-87 period can be identified:

- The industry accounted for an average of 5.9 percent of total GDP, a ratio which has declined over the period.

- There were wide differences in the importance of the sector in the various regions of the country - especially Alberta and the Territories but also in sub-provincial areas. This was true in terms of GDP and employment. Some regions, such as Ontario, produce a fairly large share of the total value of crude mineral production (see figure 3.1) but have little overall reliance on the crude mineral industry (see figure 3.2). The reverse is true of the Territories.

- The sector contributed less to total employment than it did to total GDP, representing an average of 1.1 percent of total employment.

- The sector contributed more to total exports than it did to total GDP, an average of about 15 percent of total exports. Canada is export dependent for most of its crude mineral production.

- In terms of its share in total employment, exports, and GDP, the relative importance of the crude mineral sector has declined; weak prices for minerals and a sharp decline in oil prices were partly responsible for these trends.

Some selected indicators of the importance of the crude mineral industry to Canada are shown in figure 3.3.

FEDERAL SUPPORT FOR EARTH SCIENCES R&D AND GEOSCIENCE DATA COLLECTION

Overall, the federal government's science and technology (S&T) expenditures rose by 28 percent between 1980/81 and 1987/88, and represented about 4 percent of budgetary expenditures. Federal support for the earth sciences consists largely of S&T expenditures for scientific data collection and analysis and information services. Most federal earth science S&T activities are undertaken intramurally by the Geological Survey of Canada. In addition, funds are distributed extramurally to provincial governments and to universities and industry.

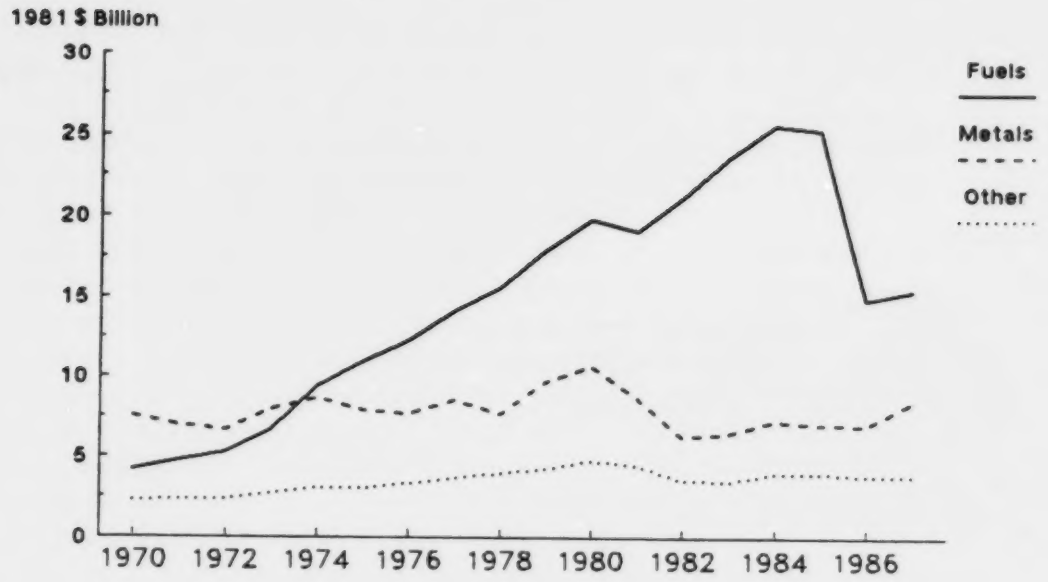

Figure 3.1 Value of Crude Mineral Production, 1970 - 1987

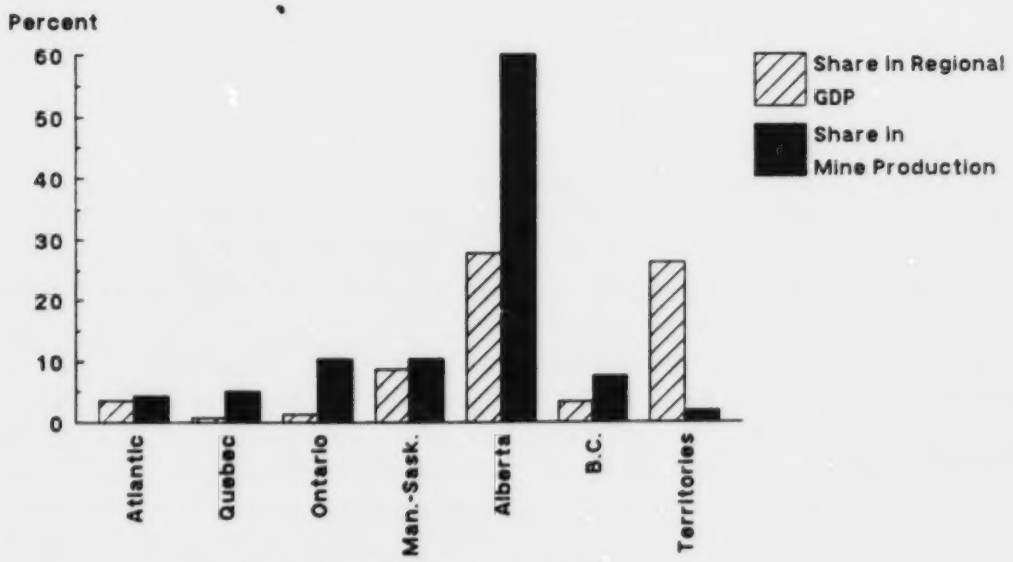

Figure 3.2 Share of the Mining and Oil and Gas Industry in Regional GDP and in Total Mine Production, 1984

Intramural Government Funding

Energy, Mines and Resources

Figure 3.4 shows EMR S&T funding by recipient in the 1980/81 to 1987/88 period. For the most part EMR funding of S&T is intramural (almost 75 percent). The principal agency within EMR which performs earth-science-related activities including R&D is the Geological Survey of Canada (GSC). Its mandate is to provide comprehensive basic knowledge of the Canadian landmass including offshore areas. This knowledge includes geological information on the nature and distribution of Canadian mineral and energy resources and assessments of geological hazards and features that may affect resource exploration and development.

A summary of EMR intramural funding related to earth science is shown in table 3.1. Between 1982/83 and 1986/87, GSC S&T expenditures rose by 49 percent to about $88 million. They accounted for more than half of EMR's interests in the earth sciences. However, these numbers are misleading, since the 1982/83 - 1986/87 period was one in which a surge in temporary or add-on funding occurred. The on-going resource base or A-base for operating funds has slowly but steadily declined since the mid-1970s and is expected to be about 70 percent of the 1976/77 level in 1992/93 as shown in table 3.2. This "worst case scenario" assumes that none of the add-on programs will be extended, and would result in a

Table 3.1 Summary of EMR Intramural S&T and R&D Budgets Related to Earth Sciences, 1982/83 and 1986/87
(1981 $ thousand)

	1982/83		1986/87	
	S&T	R&D	S&T	R&D
Geological Survey of Canada	58,834	44,714	87,570	71,851
Surveys and Mapping	23,987	1,363	24,587	5,028
Polar Continental Shelf Project	5,303	456	5,344	0
Canada Centre for Remote Sensing	29,195	28,891	31,770	18,639
Total	117,319	75,424	149,271	95,518

Source: Table 3.14, Canada Earth Science Background Study.

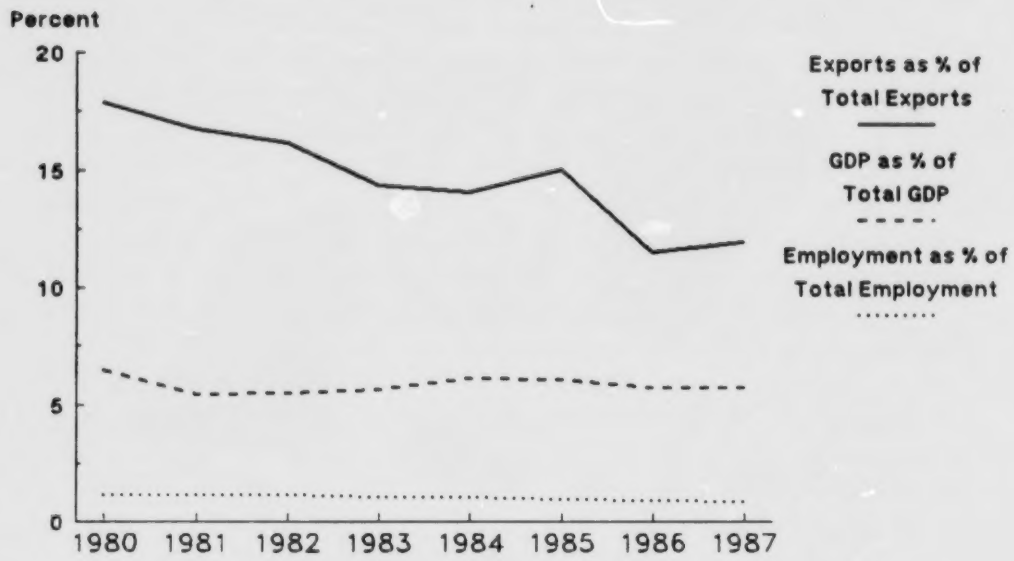

Figure 3.3 Importance of the Crude Mineral Industry in the Canadian Economy, 1980 - 1987

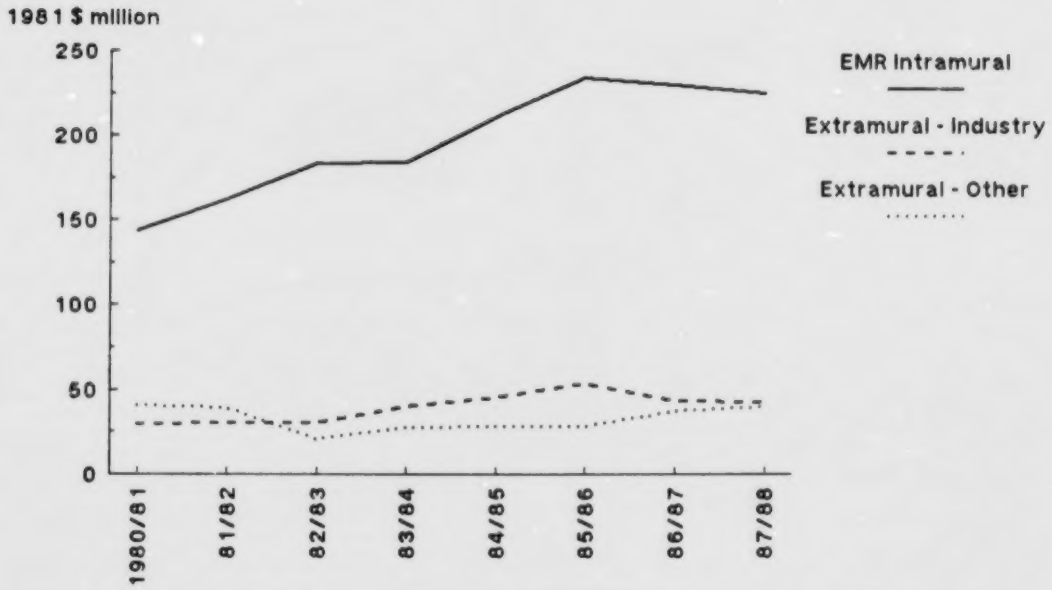

Figure 3.4 EMR Science and Technology Funding by Recipient, 1980/81-1987/88

Table 3.2 Geological Survey of Canada Total Operating Resources by Program, Worst Case Scenario (1987/88 $ thousand[a])

Year	A-Base	FGP[b] (A-Base)	Energy R&D	MDAs	NOGAP[c]	Asbestos[d]	Gaspée[e]	Boundary[f]	Total	Price Index 1987=100
1976/77	34,482	0	793	0	0	0	0	0	35,275	2.203
1977/78	35,954	0	731	0	0	0	0	0	36,685	2.031
1978/79	34,485	0	1,657	0	0	0	0	0	36,142	1.892
1979/80	31,496	0	1,061	0	0	0	0	0	32,557	1.725
1980/81	27,990	0	1,712	0	0	0	0	0	29,703	1.564
1981/82	29,433	0	1,148	0	0	0	0	0	30,581	1.381
1982/83	27,611	0	3,486	0	0	0	0	2,929	34,026	1.236
1983/84	27,968	0	7,843	0	0	0	262	530	36,603	1.256
1984/85	24,152	4,187	7,317	2,226	400	389	931	3,937	43,539	1.112
1985/86	20,541	6,726	2,943	6,739	476	615	967	5,475	44,482	1.068
1986/87	19,871	11,895	3,461	9,283	805	396	494	0	46,205	1.026
1987/88	18,568	10,479	3,158	10,306	896	0	590	0	43,997	1.000
1988/89	19,153	9,551	3,052	7,537	0	0	366	0	39,659	0.963
1989/90	17,908	9,180	2,739	2,506	0	0	0	0	32,333	0.925
1990/91	16,419	8,830	2,648	256	0	0	0	0	28,154	0.890
1991/92	16,420	8,840	2,586	0	0	0	0	0	27,487	0.855
1992/93	16,420	8,153	2,486	0	0	0	0	0	27,059	0.822

Source: Table 3.8, Canada Earth Sciences Background Study.
Note: These figures are presented in 1987 dollars. In 1981 dollars, A-base declines from $25.0 million to $17.8 million from 1976/77 to 1992/93. In current dollars, the change is $15.7 million to $29.9 million.

a 4 percent inflation per year assumed beyond 1987/88.
b Frontier Geoscience Program. Classified as an A-base activity as of 1989/90.
c Northern Oil and Gas Action Plan.
d A program focused on asbestos-producing regions of Quebec.
e A program focused on the Gaspé.
f Two programs in support of boundary disputes with the United States and France.

severe cutback in GSC's operating capacity. In fact, in 1988 the Frontier Geoscience Program (FGP) which was originally an add-on program dealing with offshore areas, was reclassified as an A-base activity and is no longer scheduled to terminate after 1989/90. The inclusion of the FGP in the A-base raises its level considerably; however, it must be kept in mind that the responsibilities of the A-base in terms of the geographical area covered by its activities are also expanded quite considerably since the offshore areas are so large. Figure 3.5 is based on table 3.2, and presents a vivid indication of the importance of add-on funding in GSC's financial resources in the 1980s. For the purposes of the graph the FGP is assumed to have been an A-base activity since its inception. Many of the other add-on programs have already terminated or are in the process of winding down, with no replacement programs in sight.

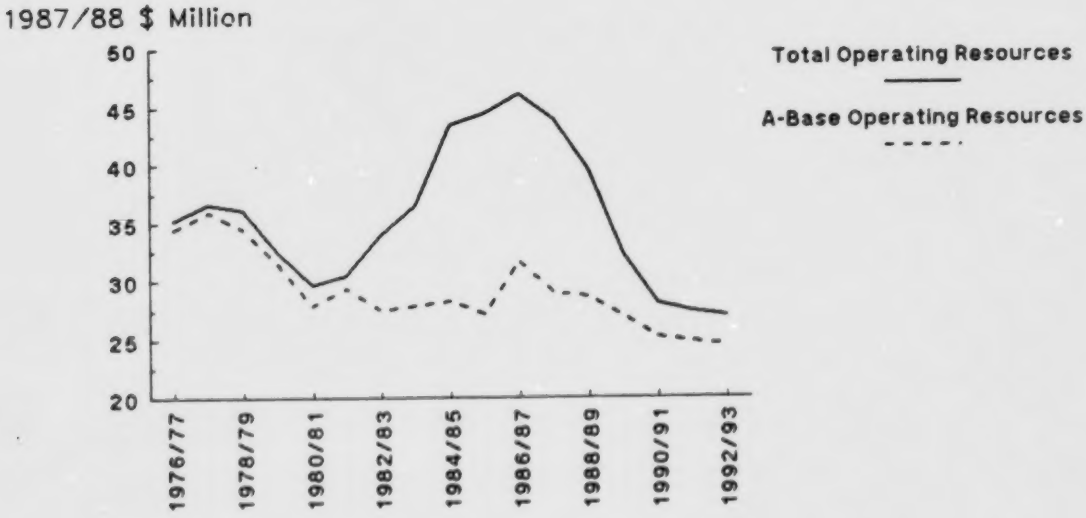

Figure 3.5 GSC Total and A-Base Operating Resources, Worst Case Scenario, 1976/77 - 1992/93

Earth-science-related activities are undertaken in three other programs within EMR's Minerals and Earth Science Program: The Surveys and Mapping Branch, the Polar Continental Shelf Project (PCSP) and the Canada Centre for Remote Sensing (CCRS). These activities are for the most part not directly related to geoscience R&D. Their S&T funding levels have shown little change in the 1982/83 - 1986/87 period. In total, EMR's earth-science-related S&T was $149 million in 1986/87. Part of this represents a small amount of extramural funding via grants in support of applied research, mainly in universities.

One significant aspect of the federal government's funding of geoscience research is the series of Mineral Development Agreements (MDAs) undertaken with all provinces and territories except Alberta, generally in a 5-year time frame beginning in 1984 or 1985. The agreements are a combination of extramural and intramural funding as the federal and provincial governments both provide funds and deliver programs. All of the MDAs include geoscience components. The total geoscience funding for 5-year life of the the MDAs is $131 million (current dollars), of which between 50 and 60 percent is provided by the federal government. The federal geoscience delivery agency is the GSC, and MDA geoscience funding handled by the GSC is included in the totals in table 3.1. As shown in table 3.2, this activity is already declining, as the agreements expire.

Other Federal Departments and Agencies

In addition to EMR, other federal organizations with intramural earth-science-related activities include the Department of Indian Affairs and Northern Development (DIAND), the Canada Oil and Gas Lands Administration (COGLA), Environment Canada, the Department of Fisheries and Oceans (F&O) and the National Research Council (NRC). It appears that the programs with some relevance to earth sciences in these departments have increased their expenditures over the 1984/85 to 1987/88 period. The largest of these programs are Environment Canada's Weather and Climate Services and its Inland Water Conservation Program, which together accounted for over $200 million in 1986/87. It is difficult to estimate just how much of this was related to earth science or to R&D. In addition to intramural support, these departments also provide small amounts of extramural R&D support through grants.

Extramural Government Funding

Federal support for extramural earth-science activities can be divided into three categories: grants for research, mainly to universities and

principally through the National Sciences and Engineering Research Council (NSERC) but also through EMR; contracts for the provision of research and technical services; and exploration incentives, generally within the tax system. This last category is not covered here but is a significant contribution to exploration activities. Support via contracting is often administered on behalf of other departments by the Department of Supply and Services so that if DSS contracts are included there is a danger of double counting. Hence the second category is covered here only through EMR's expenditure totals and in reference to international aid. EMR contract support is included in its total expenditures.

NSERC R&D Support for Earth Sciences

NSERC programs are divided into four planning elements: the research base, scholarships and fellowships, targeted research and general support. The research base support provides operating, equipment, infrastructure and special project grants according to distributions determined by discipline-based committees. Targeted research includes strategic grants and university-industry grants. General research support, the fourth element in NSERC's funding program, consists mainly of grants given to university presidents which can not be classified by discipline as can other grants. Table 3.3 and figure 3.6 summarize NSERC funding in the earth sciences. NSERC support for earth sciences was about $16 million in 1986/87, up 36 percent from 1980/81, and total NSERC support grew by 39 percent. Within the earth sciences, the category of geochemistry/geology received by far the most support. Some additional earth sciences support is provided within the civil engineering category, but is not shown here.

Table 3.3 Summary of NSERC Earth Science Support, 1980/81 and 1986/87 (1981 $ thousand)

	1980/81	1986/87
Earth Science		
Operating grants	7,854	10,184
Equipment and infrastructure grants	2,015	2,759
Strategic grants	1,695	1,588
Special projects	0	99
Scholarships/fellowships	33	264
University-industry programs	0	825
Subtotal	11,597	15,719
Total NSERC support	176,100	244,900

Source: Tables 3.18 and 3.30, Canada, Earth Science Background Study.

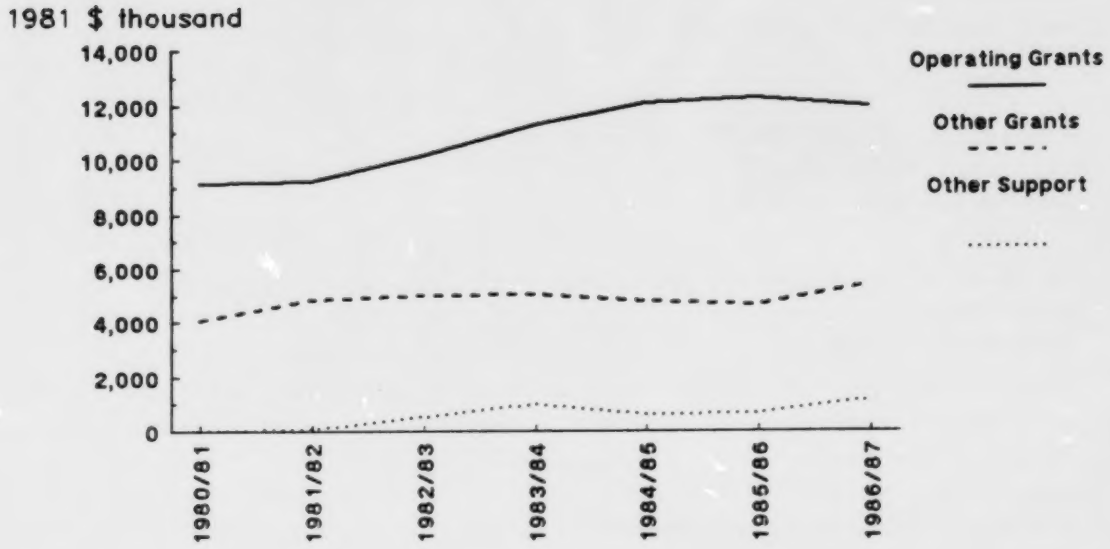

Figure 3.6 NSERC Support for the Earth Sciences, 1980/81 - 1986/87

Federal International Aid Programs Supporting Geoscience Activities

These programs do not provide R&D support per se, but rather support geoscience data collection and mineral exploration undertaken by Canadian professionals. Three organizations provide some earth-science-related funds: the Canada International Development Agency (CIDA), the Petro-Canada International Assistance Corporation (PCIAC) and the International Development Research Corporation (IDRC).

The mining portion of CIDA's assistance projects represents less than 1 percent of CIDA's budget and includes some geological survey and exploration projects. CIDA's estimated earth science expenditures totaled $19 million over the period 1980/81 to 1986/87. Most of these funds were paid to Canadian firms and non-governmental organizations. The IDRC spent about $8 million in the same period, for projects still active in 1988. Over half of these funds went to Canadian universities or firms. As a subsidiary of Petro-Canada, PCIAC has a mandate to assist developing countries in the development of their oil and gas resources. It concentrates its effort in the upstream end of the industry, often

using Canadian companies and specialists. Its project expenditures averaged about $37 million per year between 1982 and 1988, although how much was earth-science related is not known.

PROVINCIAL SUPPORT FOR THE EARTH SCIENCES

Provincial Geoscience Activities

To measure the provincial geoscience activities performed by provincial mines departments and geological surveys, the Centre for Resource Studies conducted a survey (1987 and revised 1988) of each provincial or territorial governmental body responsible for geological activities. The results are summarized in table 3.4. A-base funding can be seen to fall in seven provinces, and fell by 3.5 percent overall over the period shown. In four of the provinces, add-on funding reversed the trend and has resulted in increased spending, at least for the duration of the Mineral Development Agreements.

Total provincial geoscience expenditures have risen fairly steadily over the 1981/82 - 1985/86 period, to almost $53 million, while A-base expenditures fell from $38 to $37 million, as shown in table 3.5. Different provinces emphasize different aspects of geoscience activities and a few general trends are evident: commodity studies have been a growing focus of attention, and most provinces have emphasized mapping over geoscience data collection. As noted in the previous section, the MDAs are funded jointly by the federal and provincial governments, and the provincial contributions are included in the "total" categories in table 3.4 and 3.5.

The R&D category identified by the provinces was described as "R and D into new techniques and technology related to geosciences." It is clearly much smaller than the R&D component in the Geological Survey of Canada data in table 3.1, which includes R&D aspects of the data collection and analysis. A closer match would be achieved by including all the provincial geoscience and mapping activities in R&D. This is the approach used to estimate provincial R&D expenditures in table 3.9.

Table 3.4 Provincial Total and A-Base (or Equivalent) Geoscience Expenditures

	Total % Change 1981/82-1985/86	A-Base % Change 1981/82-1985/86	A-Base as % of Mineral Production Value Excluding Oil and Gas, 1985	A-Base as % of Mineral Production Value Including Oil and Gas, 1985	A-Base $ Per Capita 1986	A-Base $ Per sq.km.[a] 1986
Newfoundland	8.9	168.0	.34	.34	4.2	5.9
PEI[b]	n/a	n/a	na	na	0.1	1.7
Nova Scotia	61.7	90.1	.68	.68	2.1	33.0
New Brunswick	33.9	16.7	.19	.19	1.2	11.1
Quebec	23.3	-9.9	.45	.45	1.3	5.4
Ontario	23.2	-12.7	.27	.26	1.1	9.2
Manitoba	90.0	-15.0	.30	.24	1.6	2.6
Saskatchewan	-10.4	-10.4	.17	.06	1.8	2.8
Alberta	-7.6	-7.6	.42	.03	2.6	9.3
British Columbia	20.9	-16.7	.12	.09	0.9	2.6
Yukon	118.1	-2.6	1.08	1.08	22.9	1.1
NWT	1.4	1.4	.21	.15	20.6	0.3
Total provincial	21.5	-3.5	.29	.10	1.5	3.7

Source: Table 4.2, Canada Earth Science Background Study.

na Not available.
n/a Not applicable.

[a] Including land and fresh water area.
[b] Expenditures began in 1983/84.

Table 3.5 Summary of Provincial Geoscience Expenditures by Activity, 1981/82 and 1985/86
(1981 $ thousand)

	1981/82	1985/86
Geoscience data collection	7,080	8,550
Mapping	10.548	13,106
Mineral deposit and commodity studies	6,218	8,100
Publications, analysis, information, inventories, services, administration	17,826	16,929
R&D activities and support	1,338	2,039
Other	471	4,117
Total	43,480	52,840
A-Base	38,266	36,910

Source: Table 4.3, Canada Earth Sciences Background Study.

Provincial Exploration Incentives

One territory and three provinces have exploration subsidy programs: Yukon, British Columbia, Ontario and Quebec. Whereas the focus of British Columbia's exploration incentives is the extension of the economic life of existing mines, the aim of the Quebec government in its assistance is more regionally and commodity oriented and is directed at advanced stages of exploration.

INDUSTRY SUPPORT FOR THE EARTH SCIENCES

The mineral industry involved in exploration and/or earth sciences R&D consists of mineral producers, both mining and petroleum companies; junior mining or exploration companies which are generally not mineral producers; and a host of service firms involved in such activities as remote and airborne sensing, geophysical and geochemical exploration and other exploration services, and diamond drilling. In addition there are firms that develop and manufacture instruments and equipment for exploration and earth science studies.

In general, the mineral producing firms are the fewest in number and largest in terms of assets and revenues; the exploration firms are far more numerous and much smaller; and the service companies are smaller still. The metal mining industry is predominantly Canadian-owned (85 percent of equity), while the mineral fuels industry has a higher degree of foreign ownership (43 percent of equity).

Exploration Expenditures

There is a close relationship between price changes and the level of exploration expenditures, since exploration programs in large companies are generally financed out of current cash flows. However, it is important to recognize that the relationship is in fact very complex, involving other factors including profitability, investor expectations and opportunities, exchange rates, government incentive programs, other economic and political risk factors, new geological theories, and the excitement generated by new discoveries.

Mining Exploration

The mining exploration industry consists of a wide variety of companies including mineral producers, oil companies looking for non-petroleum minerals, and a large number of small firms whose only activity is mineral exploration. In 1985, mining companies represented a relatively small proportion of the total number of companies engaged in non-petroleum mineral exploration but they and their affiliates accounted for over half of mining exploration expenditures.

The overall level of non-petroleum mineral exploration has fluctuated widely in the 1980-87 period, largely as a result of metal price changes. The flow-through share (FTS) program which provided tax deductions for equity investments in exploration activities has also had a major influence on expenditure levels and location in recent years. This

Table 3.6 Summary of Exploration Expenditures in Canada, Selected Years (1981 $ million)

	1980	1984	1987
Mining			
Quebec	81	98	335
Ontario	81	99	133
B.C.	124	95	82
Other	252	114	108
Total	537	406	658
Petroleum[a]	4,579	4,204	2,091

Source: Tables 5.4, 5.7 and 5.8, Canada Earth Sciences Background Study.
[a] Gross exploration expenditures of companies responding to Petroleum Monitoring Agency survey (about 90 percent of the industry).

federal incentive was enhanced by an additional write-off in Quebec until 1986, and had a substantial effect on expenditures in Quebec, where expenditures quadrupled between 1980 and 1987. Total mining exploration expenditures rose to $658 million in 1987, from $537 million in 1980 (see table 3.6 and figure 3.7). All provinces except Ontario and Quebec had fairly substantial reductions in exploration expenditures between these two years.

Petroleum Exploration

The Canadian petroleum industry consists of three types of firms: a few large multinationals; medium-sized Canadian-owned companies; and small non-producing firms. The multinationals and a few Canadian firms, including Petro-Canada, are vertically integrated with activities in the upstream (exploration, development and production) and downstream (refining, processing and marketing) sectors. As with mining, there is also a very large group of service companies, primarily engaged in exploration and drilling services.

Over the 1980-87 period, oil and gas exploration expenditures fell dramatically, from $4.6 billion in 1980 to $2.1 billion in 1987 (see table 3.6 and figure 3.7). They fell in 1981 and 1982, rose in 1983 and 1984 and plummeted in 1986 before falling still farther in 1987. At least part of the reason for these movements has been price effects. However, the relationship between exploration expenditures and price is less clear-cut in the case of oil and gas than it appears to be for mining. The declines in exploration expenditures are related in part to uncertainty concerning OPEC's plans, and in part to the fact that Canadian oil prices do not reflect international realities.

In the 1980s a number of government incentives were used to encourage petroleum exploration. Under the National Energy Program instituted in 1980, Petroleum Incentive Payments (PIPs) were made to qualifying companies carrying out exploration. In 1986 the Canadian Exploration and Development Incentive Program (CEDIP) was introduced to replace the PIPs. It will be terminated by the end of 1989 and is being replaced by the much more complicated Canadian Exploration Incentive Program (CEIP), which also will apply to mining. Between 1981 and 1987 these incentive payments represented almost 30 percent of the gross exploration expenditures of the petroleum industry.

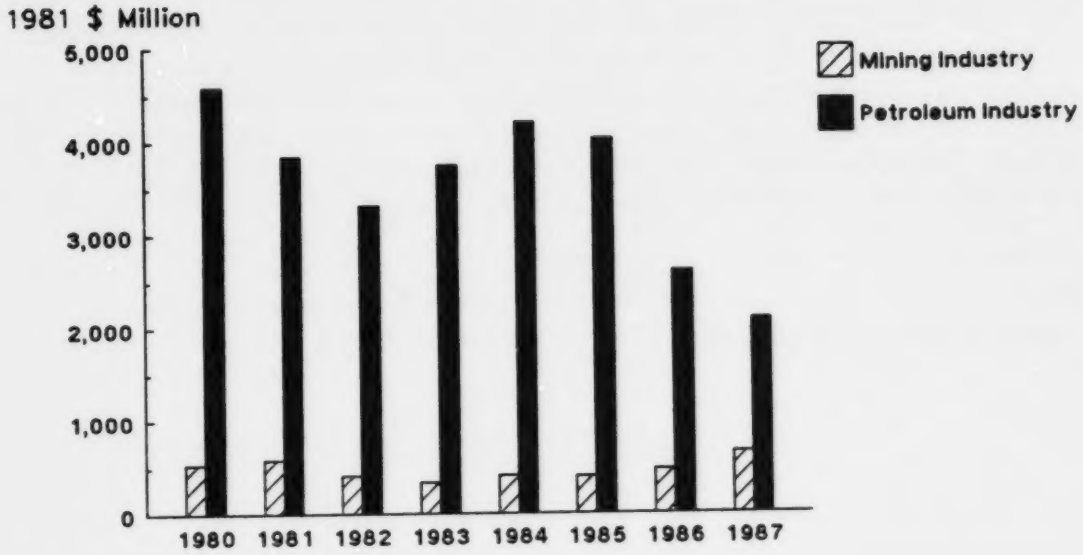

Figure 3.7 Mining and Oil Industry Exploration Expenditures, 1980 - 1987

Exploration Incentives: a comment

Exploration activities are generally carried out by business enterprises whose revenues are highly sensitive to economic conditions, present and anticipated, especially changes in prices. As a result, when prices fall, firms almost immediately cut back on exploration activities. Government incentive schemes such as flow-through shares, PIP grants, CEDIP and CEIP can stimulate exploration expenditures and can be used to reduce short-run fluctuations in exploration activities; these programs in fact did provide some stability to exploration activities in the 1980s in spite of highly volatile commodity prices. Unfortunately, because they also produce distortions in the allocation of financial resources, such programs must be carefully designed and implemented in order to achieve the desired effects.

Earth Science R&D Expenditures by Industry

Figure 3.8 shows the 1986 levels of overall R&D intensity (current intramural R&D expenditures as a percent of sales of companies performing R&D - not total sales in the sector) for selected Canadian resource-based industries, including mining and oil and gas, which have earth science interests. The mining, crude petroleum and primary ferrous metal industries are well below the all-industry average for R&D intensity. The primary nonferrous metal industry does compare favourably, but only because of the inclusion of Alcan in that category.

Figure 3.8 R&D Intensity in Selected Canadian Industries, 1986

Mining Industry R&D

No data are published specifically on earth science R&D undertaken by mining companies; only mining industry total R&D figures are available. Nevertheless, it is clear that there is a relatively low level of interest in earth science R&D in the mining industry. Mining industry total R&D averaged $40 million per year in the 1980-87 period, and it is probable that less than 5 percent of this (less than $2 million) was directed to

earth science R&D. The view that mining companies do little in the way of R&D in exploration technologies is supported by many industry observers and by some company information. However, any R&D performed in this area would, for the most part, not be eligible for tax treatment as R&D and therefore would go unreported as R&D even in internal company records.

Petroleum Industry R&D

As with the mining industry, it is difficult to ascertain how much of the total industry R&D is actually related to earth science. Total R&D in the oil and gas industry has declined significantly in this decade. After peaking in 1981 at $415 million, R&D had fallen to $123 million by 1987. In the combined category of exploration and production R&D, which includes earth-science-related R&D, expenditures fell from $104 million in 1980 to $20 million in 1987.

R&D in the Mining, Oil and Gas Service Sector

The service sector includes a wide variety of firms which provide services to the mining, oil and gas industries. In the context of exploration R&D they include primarily geophysical and other exploration consultants and contractors. The Centre for Resource Studies conducted a R&D expenditure survey of such companies in 1985. The CRS survey results combined with those of a survey of R&D in mining geophysics published annually in the Canadian Geophysical Bulletin suggest that most firms in the services category do no R&D. Those few that do undertake R&D tend to spend a substantial proportion of their revenues on R&D, on par with the R&D-intensive high-tech industries which spend as much as 10 or 15 percent of their sales on R&D (see figure 3.8 for comparison).

EDUCATION TRENDS

Post-secondary education provides Canada with the future researchers who will develop and implement the new ideas needed to maintain industrial competitiveness. Three principal indicators of university education trends in the earth sciences and in all disciplines combined are considered in order to try to determine what the future may hold for R&D. These characteristics are university funding sources and levels, the number and rank of faculty, and student enrollment at both the undergraduate and graduate level.

Trends in Overall Canadian Education

Education funding trends can only be considered at the aggregate level, since education is a provincial responsibility and the provinces do not provide information on operating funds by department or discipline. The provinces provide about 80 percent of university general operating income. In total, operating income increased by less than 9 percent between 1980/81 and 1985/86. On a per-student basis, it decreased by 10 percent, and per faculty member it increased by 3 percent over the six-year period. Trends in university operating income relative to GDP, number of faculty, and number of students are shown in figure 3.9. The number of university teaching staff has increased by about 6 percent in this period, to over 35 thousand in 1985/86. The health sciences have had the largest growth in teaching staff, followed by engineering and applied sciences. In terms of undergraduate enrollment, however, mathematics and the physical sciences (including the earth sciences) have seen the largest increases. The resource sector applied fields have seen a decline in enrollment, as have some branches of engineering, while the humanities, social sciences and biology have grown significantly.

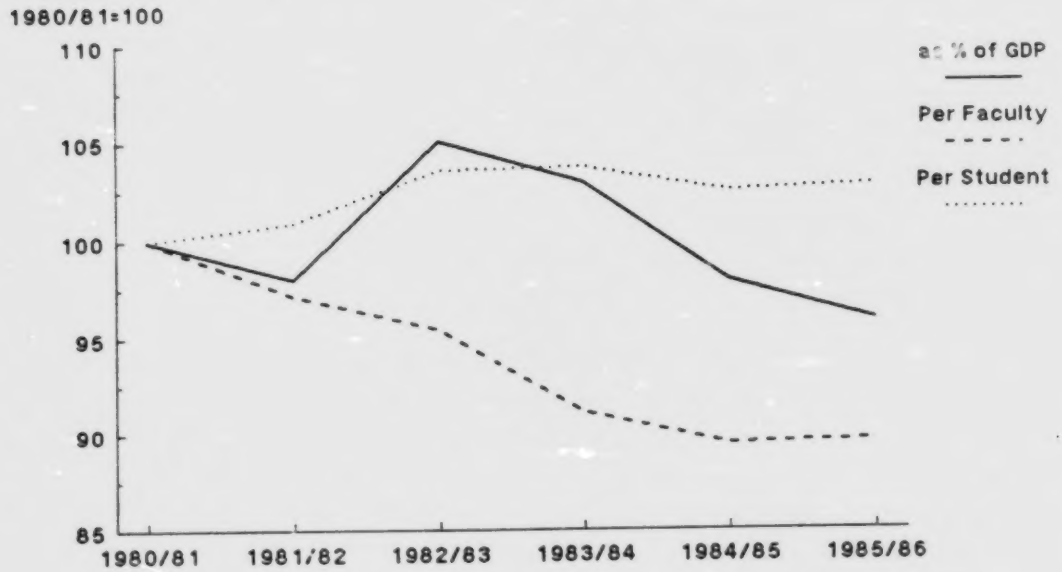

Figure 3.9 Trends in University Operating Income
1980/81-1985/86

Education Trends in Earth Science

Education in the earth sciences in Canada is conducted in a broad range of departments in universities and technical institutions, but principally in departments of earth science, geology, petroleum geology, geological science, geological engineering, and oceanography. Other departments that may include earth science interests in their curricula include civil engineering, geography, mining, mining engineering, petroleum engineering, mineral sciences, and physics.

A survey of Canadian universities by the Centre for Resource Studies indicated that 35 universities have departments or programs offering courses in earth sciences. Programs in geology are the most numerous, with geological engineering a distant second. Most of the universities also offer Master's programs and 20 awarded PhDs in earth sciences in 1985/86.

Some fields of earth science have shown sharp declines in undergraduate enrollment in the 1980s: for instance, geological engineering. Others, such as the newer fields of geophysics and geochemistry, have had strong growth in enrollment. Enrollment in the largest field, geology, grew modestly in the 1980/81 to 1985/86 period. A particularly significant trend is the decline in enrollment in the first year of earth science programs, a decline that has continued for the past three years. Enrollment in graduate programs has increased (see table 3.7), and total undergraduate enrollment in earth science programs has decreased. It is too early to know whether these trends reflect an adjustment after the surge in graduate school enrollment caused by the economic recession of the early 1980s, or represent an underlying pattern.

Table 3.7 Indicators of Support for Earth Science in Universities, 1980/81 and 1985/86

	1980/81	1985/86	% Change
Undergraduate Student Enrollment			
Earth science:			
1st year[a]	9,200	6,902	-25.0
Other years	2,813	3,217	14.4
Total	12,013	10,119	-15.8
Total all undergraduates	276,408	348,342	26.0
Graduate Student Enrollment			
Earth science	609	881	44.7
Total all graduates	44,658	54,611	22.3
NSERC Grants[b] (1981 $ thousand)			
Earth science	9,663	10,834	12.1
Total all NSERC grants	114,171	145,694	27.6
NSERC Scholarships and Fellowships[c] (number)			
Earth science	103	160	55.3
Total all NSERC scholarships	2,046	3,107	51.9

Source: tables 6.10, 6.14, 7.2, 7.5 and 7.7, Canada Earth Sciences Background Study.

[a] First year includes students in services courses who do not intend to specialize in earth sciences.

[b] 1980/81 and 1987/88 operating grants.

[c] 1981/82 and 1986/87.

Note: The NSERC data here differ from those in table 3.3 because different sources using different categories were used.

R&D IN SELECTED SCIENTIFIC DISCIPLINES

Overall R&D in Universities

University research funding represents about 13 percent of total university expenditures and increased by 40 percent between 1980/81 and 1985/86, compared with almost flat operating expenditures. Almost all university research in Canada is sponsored research, supported by specific grants for specific purposes. Sponsored research income has grown steadily since 1980/81 and its growth is compared to the growth of GDP and university operating income in figure 3.10. The main funding source (about 60 percent) for sponsored research is the federal government. Within the federal government, the major funding source for R&D in natural sciences and engineering is NSERC. NSERC peer committee grants to the earth sciences increased by 12 percent in the 1980/81 to 1987/88 period,

well below the 28 percent increase for all disciplines combined. In terms of strategic grants, which are flexible in focus and give a sense of the direction government wants research to go, there has been a decline in support for the resource-based disciplines (including earth sciences) while more high-tech categories have prospered.

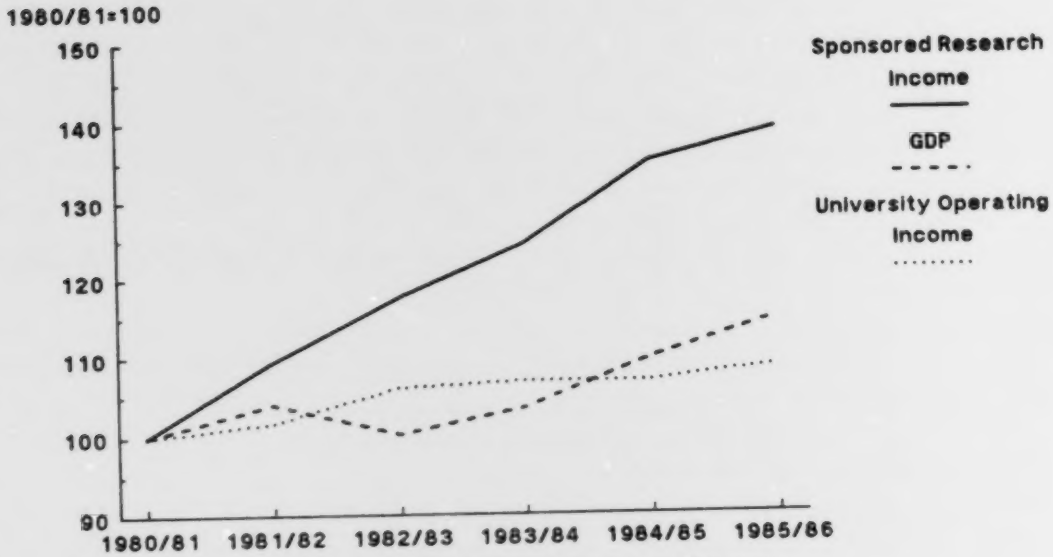

Figure 3.10 Sponsored Research Income, GDP and University Operating Income, 1980/81-1985/86

Total full-time graduate enrollment in universities increased by 22 percent in the 1980/81-1985/86 period, and natural sciences and engineering by 43 percent. Figure 3.11 shows trends in total graduate student enrollment while figure 3.12 shows the distribution of graduate students within the natural sciences and engineering.

Comparison of R&D Trends in Selected Disciplines

Scientific disciplines for the most part cannot be linked to any specific industrial sectors or activities. Even the earth-science/mineral-industry links are somewhat tenuous. Thus comparison of earth science R&D funding support with that of support for other fields of science must focus on R&D in universities where the distinctions between disciplines are obvious.

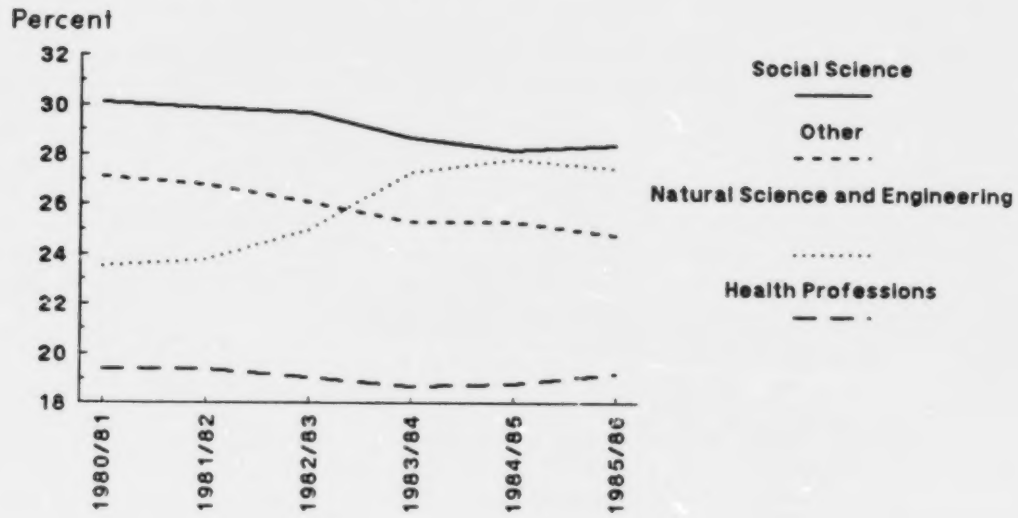

Figure 3.11 Distribution of Full-Time Graduate Students by Field of Study, 1980/81 - 1985/86

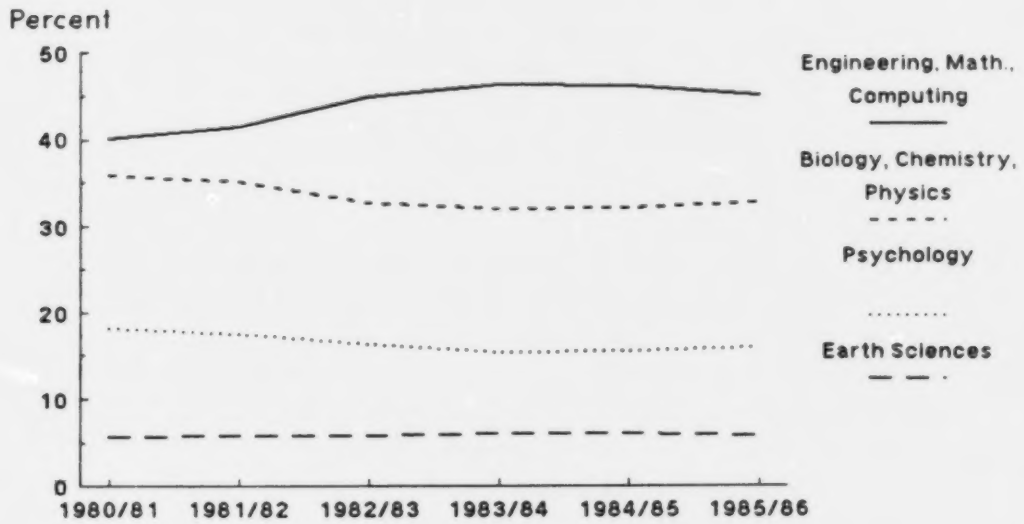

Figure 3.12 Distribution of Full-Time Graduate Students in the Natural Science and Engineering, 1980/81 - 1985/86

Two indicators of university R&D are useful: the level of funding support received by universities, especially from NSERC; and graduate student enrollment, which is an indicator of R&D levels and focus. Table 3.8 looks at both measures for selected disciplines within natural sciences and engineering. Earth sciences saw a graduate student enrollment growth of 45 percent over the period 1980-85, but received only 12 percent more in NSERC peer grants over the longer period 1980/81 - 1987/88, less than half of the total rate of increase. Its share of funding fell from 8.5 to 7.4 percent of the total; however, 7.4 percent was still larger than earth science's share of total enrollment in 1985/86. NSERC reports that its total support of earth science R&D increased by 36 percent from 1980 to 1987, compared to 39 percent for total funding (see table 3.3).

Earth Sciences R&D in Universities

The survey of universities conducted by the Centre for Resource Studies provided information on the research funding levels in geology departments. Data on funding in geography departments was also requested as considerable R&D related to earth science is conducted in these departments. The results of the survey were somewhat disappointing, due to problems of definition of research fields and to differences in department record-keeping methods, and must be used carefully. Not all universities were able to provide the requested funding information; those that did respond may have underreported the funding. The lack of systematic records on R&D funding within university departments is surprising and suggests a lack of interest on the part of department heads and deans in R&D funding trends and the implications of such trends. The survey results for the geography departments are particularly suspect, since it is not clear in some cases that a distinction was made between geography in general and earth science in particular.

R&D grant and contract funding reported by geology departments totaled in the range of $11 million to $15 million per year in the 1983-86 period. Most of the funds were provided by the federal government mainly through NSERC. Industry funding of university research was about 10 percent of the total. Earth-science-related R&D funding in geography departments was in the $2 million to $4 million range per year in this period, with NSERC and provincial governments providing similar amounts.

As noted, graduate enrollment in the earth sciences has shown a fairly steady increase, with a 45-percent rise in the 1980/81 to 1985/86 period, double the growth in total graduate enrollment. Within the earth sciences, the strongest subdisciplines are economic geology, sedimentology, petrology, structural and tectonic geology, physical geochemistry and exploration geophysics.

Table 3.8 Comparison of R&D Funding by Selected Discipline, 1980-86.

	Graduate Enrollment[a]		NSERC Total Grants by Committee		
	% of Total 1985/86	% Change 80/81-85/86	% of Total 1980/81	% of Total 1987/88	% Change 1980/81-1987/88
Earth Sciences	5.9	44.7	8.5	7.4	12.1
Biology	16.8	25.3	24.3	24.7	29.9
Chemistry	9.3	38.4	14.6	11.6	1.0
Physics and space	6.8	37.9	16.8	17.3	31.1
Mathematics, statistics and computing	12.2	66.1	7.9	9.8	57.6
Engineering	33.0	59.2	23.2	24.4	34.4
Total all disciplines[b]	100.0	43.0	100.0	100.0	27.6

Source: Tables 7.2 and 7.7, Canada Earth Science Background Study.
a In Natural Sciences and Engineering.
b Including psychology and other.

COMPARISON OF R&D EXPENDITURES IN OTHER RESOURCE SECTORS

To put the analysis of earth sciences R&D into broader perspective, a comparison of R&D expenditures in the various resource sectors in Canada is presented here. The three major resource sectors in Canada are minerals (divided into petroleum and non-petroleum), agriculture (including fisheries) and forestry. Because of the way Statistics Canada data are presented, and to ensure comparability across sectors, it has been necessary to consider not only the crude products component of these sectors but also to include the processing and in some cases the fabricating components. Unless otherwise indicated, the following analysis deals with the complete sectors, not just the crude product components.

Economic Contribution of the Resource Sectors

In general, the resource sectors as a whole have decreased their share of total GDP over the past decade from 25 percent in 1975 to just over 17 percent in 1987. This trend is evident in figure 3.13 (figure 3.14 shows the contribution of just the crude product component of these sectors to GDP, excluding the processing and fabricating stages). The agricultural sector has contributed the most to GDP in this decade, while forestry has contributed the least. The resource sectors' contribution to exports far outweighs their contribution to GDP, although it is declining. In 1980 they accounted for over 60 percent of exports, but by 1986 this had fallen to slightly more than 45 percent. In terms of employment, the resource sectors show still more variation. In 1985, agriculture provided the most jobs by far (with over 700,000 employees). The mineral and forestry industries were approximately equal (250,000 and 268,000 jobs, respectively), while the petroleum industry provided only 86,000 jobs. Some provinces, regions and communities are highly dependent on the resource industries for employment and economic activity.

Resource Sector R&D

A summary of some of the major funding sources for R&D in the resource sectors is shown in table 3.9. It is virtually impossible to arrive at firm figures representing the level and intensity of R&D funding - the data are simply too sparse. The figures in table 3.9 are not additive and are by no means all-inclusive. They are presented only as an indication of funding sources and levels in the various sectors.

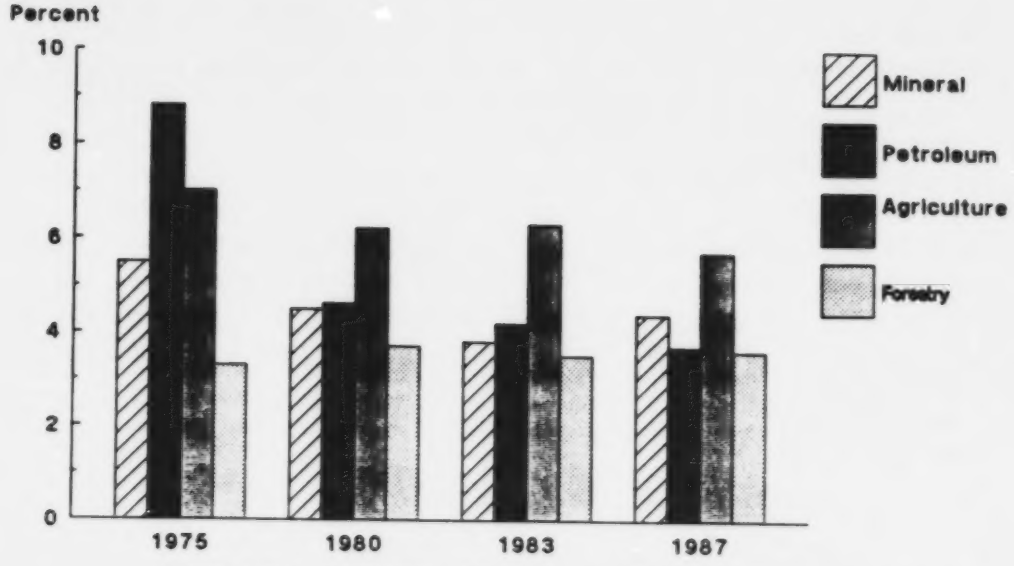

Figure 3.13 Contribution of the Resource Sectors to GDP, Various Years (Sector GDP as % of Total GDP)

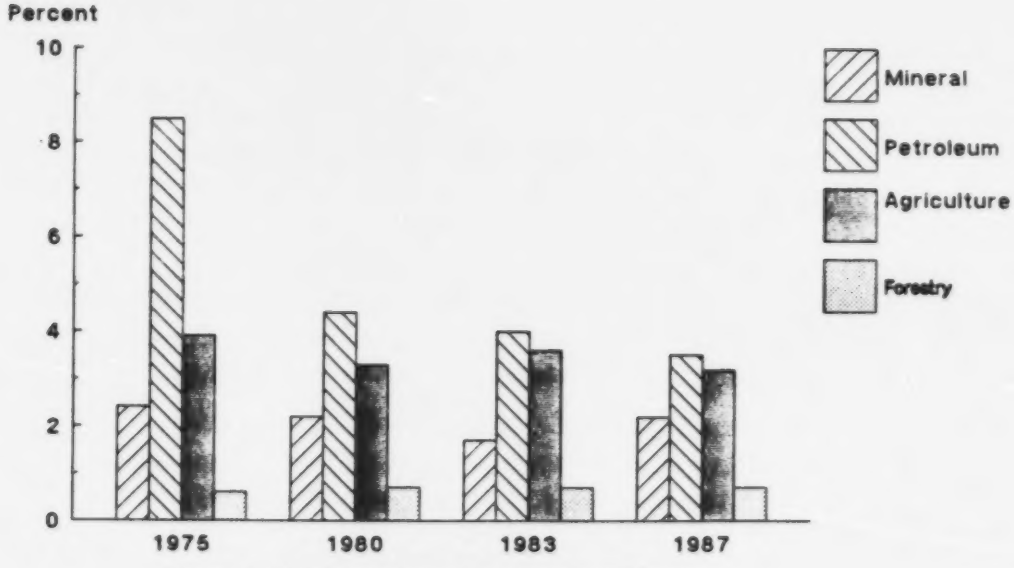

Figure 3.14 Contribution of the Primary Resource Sectors to Total GDP, Various Years, Primary Sector GDP as % of Total GDP

Table 3.9 Summary of Major Resource Sector R&D Funding

Sector	Source	Yearly Average Funding (1981 $ Million)	Percent Change Over Period	Period	Yearly Average As % of 1987 Sector GDP[a]
Earth Science: Geoscience and Exploration	Federal				
	GSC total	61	88	1982/83-1986/87	0.3
	GSC A-base operating	19	-29	1980/81-1986/87	n/a
	Provincial GS				
	Total	48	22	1981/82-1985/86	0.2
	A-base	39	-4	1981/82-1985/86	0.2
	Industry:				
	Mining exploration	474	22	1980-87	6.0
	Oil and gas exploration	3,963	-57	1980-87	30.0
Earth Science: R&D	Federal				
	GSC	51	86	1982/83-1986/87	0.2
	NSERC total ES	14	36	1980/81-1986/87	0.06
	EMR grants	0.6	-23	1980-87	0.0
	Provincial surveys	21[e]	25[e]	1981/82-1985/86	na
	Industry	2[e]	na		na
Minerals	Federal				
	CANMET[b]				
	Total	61	-12	1985/86-1987/88	0.5
	A-base	33	-12	1985/86-1987/88	0.3
	EMR grants[c]	0.7	-21	1980-87	0.01
	NSERC mining	0.2	na	1980/81-1986/87	0.0
	metallurgy	4	91	1980/81-1986/87	0.03

Table 3.9 Summary of Major Resource Sector R&D Funding (continued)

Sector	Source	Yearly Average Funding (1981 $ Million)	Percent Change Over Period	Period	Yearly Average As % of 1987 Sector GDP
	Provincial				
	MDA[c]	1	na	1984-91	0.01
	CRM	6	17	1980/81-1987/88	0.9[d]
	Alberta (ARC coal)	2	16	1982/83-1987/88	0.2[f]
	Industry				
	Mining	42	-26	1981-87	0.5
	Metals	99	-5	1981-87	2.4
	Nonmetallic	11	38	1981-86	0.6
Petroleum (primary)	Federal	na	na		na
	Provincial	na	na		na
	Industry	56	-70	1980-87	0.4
Agriculture (primary and processing)	Federal				
	Agriculture Canada	245	61	1980/81-1986/87	1.1
	Agriculture minus Forestry	na	na		0.9[e]
	Federal/provincial agreements[g]	10	na	1982-90	0.05
	Provincial				
	Ontario-ARI[h]	26	-1	1981/82-1986/87	na
	Quebec	14	110	1980/81-1986/87	na
	Industry	62	22	1980-87	0.3

Table 3.9 Summary of Major Resource Sector R&D Funding (continued)

Sector	Source	Yearly Average Funding (1981 $ Million)	Percent Change Over Period	Period	Yearly Average As % of 1987 Sector GDP
Forestry (primary and processing)	Federal				
	CFS[i]	57	23	1984/85-1986/87	0.8
	PRUF[j]	2	na	1985	0.03
	Forest Dev. Agreements[k]	na	na		na
	Provincial	na	na		na
	Industry	15	20	1980-87	0.2
	PAPRICAN[l]	14	9	1980-86	0.2

Sources: Various tables in Canada Earth Sciences Background Study; GDP values from table 8.2 in source cited.

na Not available.
n/a Not applicable.

[a] Sector GDP for Earth Sciences is taken as primary minerals plus primary petroleum.
[b] CANMET'S mineral technology expenditures, taken as 100% R&D for this table.
[c] Mining and mineral technology.
[d] $6 million as percent of Quebec 1984 mining GDP.
[e] Author's estimate.
[f] $2 million as percent of Alberta 1984 mining (excluding oil and gas) GDP.
[g] Included in Agriculture Canada above. Current $.
[h] ARI - Agricultural Research Institute.
[i] CFS - Canadian Forestry Service.
[j] PRUF - Program of Research by Universities in Forestry.
[k] Forestry Development Agreements involve relatively little R&D. Total funding 1982-90 is federal $421 million and provincial $406 million current, mainly for forest management.
[l] PAPRICAN - Pulp and Paper Research Institute of Canada (joint industry and government funding).

Oil and gas exploration expenditures are extremely high in relation to value-added, compared to mining expenditures. (This reflects in part the expectation of very major petroleum finds, and the relatively low production cost.) In R&D expenditures, the conspicuous figures are Agriculture Canada's support of agricultural R&D, and industry support for metals R&D which is largely from Alcan. The R&D intensity numbers (yearly average R&D funding as percent of GDP, within the relevant part of the sector) should not be cited as absolute indicators of R&D intensity, since the R&D funds are simply averages of crude aggregates over various time periods. They do give some sense of relative intensities.

Comparing the contribution of each sector to total industry R&D and total GDP in 1987 is instructive (see figures 3.15 and 3.16 which compare these measures for each sector in its entirety and for the combined primary and processing components of each sector). Both the mineral and petroleum industries contribute more to total R&D than to GDP. The reverse is true of forestry and agriculture and although the latter is the most important resource sector in terms of GDP contribution, its industry nevertheless makes the smallest contribution to R&D of any resource sector. This is largely a function of the small size of most agricultural establishments. The ratio of current intramural R&D expenditures as a percent of sales in the resource sectors indicates that they are generally at or below the average industrial R&D intensity for Canada, and well below the levels needed to maintain competitive position in technologically intensive industries.

Research in the Mineral and Petroleum Sector

The chief federal government agency supporting mining, metallurgy and energy R&D is EMR, specifically the Canada Centre for Mineral and Energy Technology (CANMET). Most of CANMET's activities are defined as R&D and, in addition to its budgetary expenditures, it administers the mining and mineral technology component of the federal share of the MDAs. CANMET's expenditures in 1987/88 were $74 million, down from the 1985/86 figure of $79 million in current dollars, and were concentrated in mineral processing and fuels technology. Other federal government programs support R&D in this sector including the National Research Council's extramural support for industrial R&D with a focus on technology transfer from government and universities to industry.

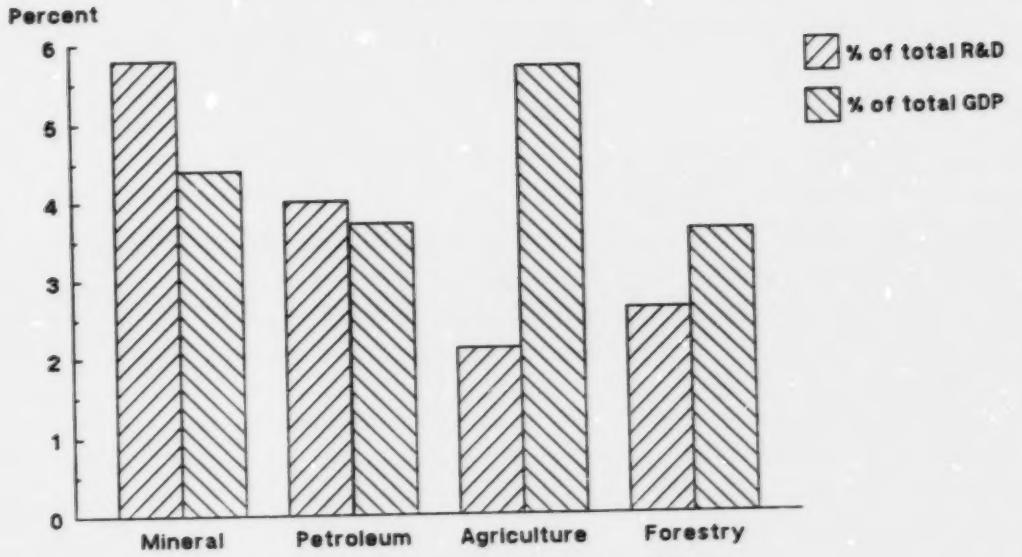

Figure 3.15 Contribution of the Resource Sector to Total GDP and Total Industry R&D, 1987

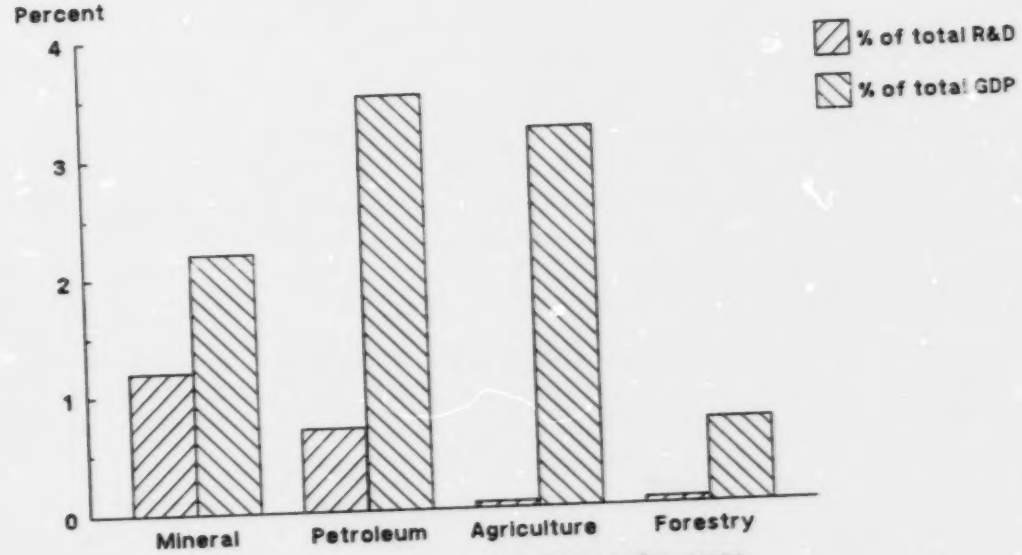

Figure 3.16 Contribution of the Primary Resource Sectors to Total GDP and Total Industry R&D, 1987

Of the provinces, Quebec is the only one with a government-owned R&D facility exclusively for research in mineral technology, the Centre de Recherche Minérale. Alberta is very active in energy research, including coal. New Brunswick's Productivity Council conducts mineral-related research in processing. Most activity in the other provinces is tied to the MDAs.

Research in Agriculture

Federal research in agriculture is based in the Research Branch of Agriculture Canada. The department's S&T expenditures represent about 25 percent of the total expenditures and of this over 85 percent is R&D ($273 million in 1987/88). Extramural support for research in industry and universities is very small, amounting to only a few percent of its total R&D expenditures. Subsidiary federal-provincial agreements for agriculture and food development administered under the Economic and Regional Development Agreements have been signed by six provinces with two others in the process of reaching an agreement. These agreements include funding for a substantial component of applied research in agriculture (about $90 million current dollars in the 1982-1990 period).

It is generally quite difficult to obtain data on provincial and industrial research in agriculture. Only Ontario and Quebec have easily identifiable expenditure programs. Ontario funds agricultural research through the Agricultural Research Institute of Ontario which had a fairly stable average budget of $26 million per year in the 1981/82 to 1986/87 period. Over half of this budget is covered by a contract agreement with the University of Guelph. In Quebec the budget appropriations of Agriculture, Pêcheries et Alimentation Quebec have more than doubled between 1980/81 and 1986/87 and have averaged $14 million per year.

Research in Forestry

Federal activity in forestry R&D is undertaken by the Canadian Forestry Service (CFS) which also administers a program of grants to universities for forestry research. Since 1983, the CFS has been part of Agriculture Canada. CSF total expenditures increased from $53.5 million in 1980/81 to $232 million in 1986/87. Research expenditures from 1984/85 to 1986/87 averaged $57 million per year, and increased by 23 percent over the 3-year period. Federal-provincial Forest Development Agreements have been signed with eight of the provinces but these are directed more at forest management than at research. The forest industry is unique among the resource industries in having its own cooperative research organization, the Pulp and Paper Research Institute of Canada (PAPRICAN), a joint

venture of the federal government, McGill University, the University of British Columbia and the Canadian Pulp and Paper Association. PAPRICAN spent an average of about $14.5 million per year between 1980 and 1986.

CONCLUSION

Research in the earth sciences is an important aspect of the overall development and search for new opportunities in the mineral industry. The mineral industry in Canada has become relatively less significant in the overall Canadian economy over the past eight years, but it nevertheless still retains an important role. It plays a substantial role in Canadian exports and, although it represents a minor proportion of total employment, it is a major source of jobs in certain areas.

The mineral industry is in its mature phase; Canada has good mineral potential, along with the technological ability to develop it. However, in recent years demand changes, price declines, and increased competition from other world suppliers have adversely affected the industry. In such an environment, R&D, including earth sciences R&D, is crucial to maintain competitive position and to realize the industry's long-term potential. Nevertheless, it is not clear that the major R&D funders, in government and especially in industry, appreciate the need for a strong and focused R&D effort in earth sciences.

The major source of earth-science-related R&D effort is the federal government. The Geological Survey of Canada has played a major role in earth sciences research for many decades; however, its contribution will be constrained by the steady decline in its A-base funding and the termination of many of the add-on funding programs that were introduced in 1980s. The federal government also provides extramural support for earth science R&D, principally through NSERC. The earth sciences have maintained a fairly constant level of NSERC support in real terms, but a declining share of total funds. Total federal R&D support for earth sciences in 1986/87 was in the order of $115 million ($96 million by EMR including $72 million by the GSC; $19 million in NSERC support). Support in other federal departments, through international aid and through extramural EMR funding will increase this figure. When compared to total mining, oil and gas industry GDP of $21 billion in 1986, it appears that federal support for earth sciences represented about 0.55 to 0.65 percent of GDP.

All provinces and territories undertake geoscience activities and their expenditures have risen fairly steadily in this decade. However, as with the federal expenditures, part of this represents add-on funding

(mainly the MDAs) rather than A-base or on-going funding which has decreased overall in the 1981/82 - 1985/86 period. This implies that provincial geoscience R&D will decline unless A-base funding is increased or new add-on funding comes on line. In 1985/86, provincial geoscience activities of about $53 million represented about 0.25 percent of mining, oil and gas industry GDP ($21.6 billion in 1985).

It appears that very little R&D in earth sciences is conducted by industry, with the exception of that performed by a few equipment manufacturers. This is an alarming conclusion, given that there is a definite need for earth science research to improve the efficiency of mineral exploration in order to maintain economic mineral reserves. For the most part, industry has left government as the major supplier of earth science R&D funds. In total it appears that earth science R&D amounts to considerably less than one percent of mineral industry GDP.

Overall funding levels of R&D are one important indicator of the importance attached to earth science research. Another is the focus of university research and teaching. It is in universities that much of the fundamental research is done, and it is also in universities that the future researchers and innovators will be found. There is no clear indication of how the university emphasis on earth sciences has fared in relation to other disciplines. In terms of graduate student enrollment, the earth sciences have done better than average. However, first-year undergraduate enrollment in geology has been dropping quite substantially; this could have serious implications for the long-term viability of geology and earth science departments if the trend persists.

In summary, the focus of government R&D has shifted away from the resource sectors. However, some resource sectors do better than others. Agriculture does relatively best in terms of government R&D support, with the highest intensity in terms of sector GDP and the fastest rate of increase.

All the primary resource industries spend under 1 percent of sales on R&D; in most cases, under 0.5 percent. The mineral industries undertake a modest amount of intramural research (primarily in mining and metals rather than earth sciences). The petroleum industry has cut its R&D expenditures back sharply, and the forestry industry has held steady, at about the same level of R&D intensity as the mineral sector. Industrial R&D as a percent of GDP in all the resource sectors remains below the industrial average and is too low and too fragmented to support major technological innovation.

CHAPTER 4. INTERNATIONAL COMPARISONS: THE ECONOMIC CONTEXT

This chapter will examine where Canada and the seven other OECD countries studied stand in terms of the first two factors identified in the framework for comparison: the mineral industry life cycle and import/export dependence. Tables 4.1 and 4.2 present summary statistics characterizing the economy, the mineral sector and the contribution of the latter to the former in each of the eight countries. As elsewhere in this report, the reader is warned of problems of comparability, reliability, and varying time periods in the data.

STAGE IN LIFE CYCLE

None of the countries included in this study are in the initial stage or second stage of early and rapid growth in their mineral industries' life cycles. Most are in the decline phase: some have recently entered it or are about to enter it, and others are well towards the later stages of the phase. The stage in the mineral industry life cycle in each country varies by commodity, but overall generalizations are possible.

Canada is in the third or mature phase for many of its mineral commodities. As noted in chapter 2, this phase is characterized by economic viability and growth potential and can last many decades, or even centuries. Commodity-by-commodity placement on the life cycle would require evaluation of reserves, location of producers on a cost curve, and location of each commodity on demand and intensity-of-use curves. The cyclical downturn in the Canadian mineral sector since the early 1980s has been misread by many observers as a permanent decline. Rather than a decline, it represents a structural readjustment to a new plateau, in response to changing circumstances of supply, demand, exchange rates, and relative prices for mineral commodities. Canada's excellent geological potential, and the demonstrated ability of the Canadian mining industry to respond when needed with technological improvements and cost-cutting measures to maintain competitive position, confirm that the industry has a long future ahead of it. This view is reinforced by a recent study by Leo Verleun and Brian Mackenzie, which demonstrates that mineral deposits in the north of Canada, where the potential has barely been tapped, are more economic and offer a better potential rate of return than deposits in the south.[1] There will be shifts in location and in commodities, but the Canadian mineral industry has good long-term potential.

1. Leo Verleun and Brian Mackenzie, Mining Potential in Northern and Southern Canada: A Comparison of the Quality and Viability of Base Metal Resources (Kingston, Ontario: Centre for Resource Studies, 1988.)

Table 4.1 Measures of Crude Mineral Industry Economic Activity: GDP and Value of Crude Mineral Production, 1985 (value in 1985 US$ billion or percent) or 1980-85 (% change*)

	Canada	Australia	Finland	France	West Germany	Sweden	United Kingdom	United States
Total GDP								
Value	316.7	155.1	54.0	510.3	625.0	100.2	454.3	3,946.6
% change	2.9	3.1	2.7	1.3	1.3	1.8	1.8	2.5
Per capita	12,577	9,847	11,024	9,251	10,243	11,994	8,026	16,494
Crude Mineral GDP								
Value								
Mining	6.6	4.5[b]	0.2[e]	2.5[d]	5.8[d]	0.5	na	26.6
Oil and gas	8.5[a]	2.1[b]	0.0	1.2[d]	.3[d]	0.0	na	97.1
Total	15.1	6.6[b]	0.2[e]	3.7[d]	6.1[d]	0.5	29.8	123.7
% of total GDP								
Mining	2.1	na	.4[e]	.5[d]	1.0[d]	.5	1.2[b]	.7
Oil and gas	4.0[a]	na	0.0	.2[d]	0.5[d]	0.0	5.4[b]	2.5
Total	6.1	6.0[d]	.4	.7[d]	1.1	.5	6.6[b]	3.1
% change								
Mining	4.4	na	-.6[e]	-3.4[c]	2.4[c]	4.2	na	-1.6
Oil and gas	1.2[a]	na	n/a	5.4[c]	9.1[c]	n/a	na	-1.4
Total	2.0	7.2	-.6	-1.1[c]	3.8	4.2	6.0	-1.7
Value of Crude Mineral Production								
% change								
Mining	-4.4	0.3[f]	4.4	-3.6	.1	4.7	4.5	-5.2
Oil and gas	5.1	16.8[c]	n/a	4.3	2.7	n/a	10.8	-0.5
Total	.9	1.5[f]	4.4	-2.0	.3	4.7	5.6	-2.2

Source: Background Study for each country; OECD, Industrial Structure Statistics, various years; OECD, National Accounts, 1973-1985, volume II; US Department of Commerce, Statistical Abstract of the United States, 1988; and Australian Bureau of Statistics, Yearbook, various years.

* Average of annual percent changes based on real domestic currency values.

na Not available. n/a Not applicable.

[a] Services incidental to mining included in oil and gas.
[b] Estimates based on value added, 1984 for Australia and 1983 for the United Kingdom.
[c] 1980-1984.
[d] 1984.
[e] Metal mining only (metal mining accounts for about 95% of total mining).
[f] 1980-1983.

Table 4.2 Trade and Employment Impacts of Crude Mineral Sector, 1985 (value in 1985 US$ billion or percent) or 1980-85 (% change*)

	Canada	Australia	Finland	France	West Germany	Sweden	United Kingdom	United States
Exports								
Total								
% of GDP	26.9	14.8	29.8	23.6	29.2	30.1	22.4	5.1
Crude Mineral								
Value								
Mining	5.5	5.3	.1[a]	.57	1.9	.6	2.0[a]	5.9
Oil and gas	7.3	1.2	.0	.04	.9	.0	16.8[a]	.5
Total	12.8	6.5	.1[a]	.6	2.8	.6	18.8[a]	6.4
% of total								
Mining	6.5	24.9	.3[a]	.48	1.1	2.0	2.1[a]	2.9
Oil and gas	8.6	5.3	.0	.02	.5	.0	17.4[a]	.2
Total	15.1	30.3	.3[a]	.5	1.6	2.0	19.4[a]	3.1
% Change								
Mining	-1.6	na	-.7[c]	3.3	na	6.8	-5.5[d]	-8.3
Oil and gas	1.8	na	n/a	68.1	na	n/a	22.7[d]	-16.7
Total	0.0	11.7	-.7[c]	3.8	-1.7	6.8	16.7[d]	-9.2
Import Dependency								
Metallic ores and concentrates	no	no	yes	yes	yes	yes	yes	yes
Coal	no	no	yes	yes	no	yes	yes[f]	no
Oil and gas	no	no	yes	yes	yes	yes	no	yes

Table 4.2 Trade and Employment Impacts of Crude Mineral Sector, 1985 (value in 1985 US$ billion or percent) or 1980-85 (% change*) (continued)

	Canada	Australia	Finland	France	West Germany	Sweden	United Kingdom	United States
Employment								
% of total employment								
Mining	.7	1.1[a]	.3	.5[a]	.9	.3	1.0[a]	.3
Oil and gas	.3	.1[a]	0.0	.04[a]	.03	0.0	.1[a]	.5
Total	1.0	1.2[a]	.3	.6[a]	.9	.3	1.1[a]	.9
% change								
Mining	-4.5	na	.3	-4.6	-2.4	-4.0	-6.9[d]	-5.7
Oil and gas	4.8	na	n/a	.6	.3	n/a	15.6[d]	1.6
Total	-2.3	2.0[d]	.3	-4.4	-2.4	-4.0	-5.2[d]	-1.6

Source: Background Study for each country; OECD, Industrial Structure Statistics, various years; OECD, National Accounts, 1973-1985, volume II; US Department of Commerce, Statistical Abstract of the United States, 1988; and Australian Bureau of Statistics, Yearbook, various years.

* Average of annual percent changes based on real domestic currency values.

na Not available.
n/a Not applicable.

a 1984.
b Metallic minerals, coal and petroleum and products.
c 1981-1984.
d 1980-1984.
f UK coal imports are about 12 percent of domestic production.

Australia is the only other country among those studied to also be in the mature phase of its mineral industry life cycle. The Australian mining sector has grown rapidly in recent decades. Although its importance has declined somewhat in the 1980s, it remains an important economic sector. It is like the Canadian industry in terms of GDP and employment, but is much more significant in exports. Also like Canada, Australia has substantial reserves, with good long-term economic potential.

All the other countries in this study may be considered to be in the decline phase of the mineral industry life cycle, although the United States might instead be classified as approaching the end of its mature phase. The United States has a history of mineral production not unlike that of Canada and Australia, with similar commodity distribution but larger production volumes. The primary mineral industry plays a relatively smaller role in the larger economy in the USA than in Canada and Australia, although processed minerals and metals are similar in terms of contribution to GDP. The United States mining industry was characterized by falling production values and volumes in most commodities through the first half of the 1980s. There has been some recovery since 1985, but prospects for long-term renewal and growth are not good, due to depletion, environmental regulation, and other cost pressures. Canada faces some of these same pressures, which contributed to the downturn in the Canadian mineral sector in the first half of the decade.

In Sweden, mining's contribution to GDP is insignificant, far below that of Canada, Australia and the United States. Sweden is in the early phases of decline in metal mining. It has no coal and no oil and gas sector. Mining contribution to GDP actually increased somewhat in the early 1980s in Sweden, due to growth in the nonferrous and nonmetallic sectors, while iron ore production has fallen and substantial rationalization has occurred in the iron mining industry. Although there is little statistical evidence yet of the decline of the economic importance of the mining sector, depletion effects and rising costs will take their toll in the next decade. The metal mining industry is expected to cease altogether early in the next century, unless major new discoveries are made. Sweden is heavily dependent on imports of metallic and energy minerals to support its very strong primary and fabricated metals industries. Although the geoscience data base in Sweden has been characterized as inadequate as a support to efficient mineral exploration by some in the exploration sector, the government geoscience activities and exploration subsidy programs are declining. Exploration for nonferrous metals and gold appears to be on the increase.

The remaining four countries studied, Finland, France, West Germany and the United Kingdom, can all be classified as being well advanced in the decline phase of mineral production, although there are exceptions for certain commodities in some of these countries. For example, in the United Kingdom the various mineral sectors are in quite different stages: metal mining almost ceased in the previous century, and is soon expected to expire altogether; coal mining's continued importance is more a matter of political considerations related to employment and security of supply than of economic reality. This may change, with privatization and continued rationalization, and lead to a further decline in UK coal production. The industrial minerals sector remains important. These three sectors together contribute relatively little to British GDP; nevertheless, the mineral sector as a whole remains quite important in the economy due to oil and gas. North Sea oil and gas have provided a tremendous boost to the UK economy, but are approaching the later stages of maturity. Mineral exploration is almost non-existent in the UK; geoscience expenditures are dropping, and the mining exploration subsidy program has been dropped. Complications in ownership of mineral rights may have played an even greater role in the decline of exploration activity than resource potential. Oil and gas exploration has declined as well, and is shifting its emphasis to onshore sites.

Finland, France and West Germany are similar in terms of their mineral industries' place in the life cycle. In each, the mineral sector contributes little to overall economic activity, while the primary metals and fabricating industries play a major role. In all three, the metal mining industry, after centuries of activity, is nearing an end due to resource exhaustion. An uneconomical coal industry continues to exist in France and especially in Germany where, as in the United Kingdom, subsidization of the industry is a means of regional economic support. In each of these three countries, the industrial minerals sector remains relatively important; it shows signs of increased exploration and production activity in both Germany and Finland. Finland does not have an oil and gas sector. France and West Germany do, but it is of little importance in the economy. All three countries have seen reductions in domestic exploration, and have turned to mineral exploration abroad to secure access to mineral and energy raw materials. There has recently been a decline in such offshore activities by Finland and Germany.

In summary, the mineral industry in Europe is in decline: exploration activities are declining; the complete demise of the metal mining industry is approaching; the coal industry remains more important politically and regionally than its overall economic potential would justify; the smelting and refining sectors are suffering (to a lesser extent in Finland and

Sweden than in the UK, France and Germany) because of raw material import dependence, environmental costs, and structural changes in supply and demand factors; and petroleum has had what appears to be a short-lived period of importance in the United Kingdom. Only the industrial minerals sector displays any potential for continued or increased activity. This sector is important in domestic economic activity, but rarely plays an important role in exports.

The United States faces a situation that is somewhat similar to that in Europe, although the mineral sector there retains greater significance in the overall economy. In contrast, the mineral sector in Canada and Australia remains quite important. In 1985 the sector accounted for about 6 percent of GDP in both these countries, while it contributed about 1 percent or less to the GDP of the continental European countries and about 3 percent to United States GDP (see table 4.1 and figure 4.1). The sector also contributed over 6 percent of total GDP in the United Kingdom as a result of North Sea oil and gas, which has a limited future. If we consider only the mining sector, and exclude oil and gas production (and coal production in the United Kingdom and West Germany) the position of Canada with the respect to the other countries becomes even clearer. Mining GDP contributed on the order of 0.5 percent of GDP in each of the European countries and the United States in the mid 1980s. In comparison, mining contributed over 2 percent of GDP in Canada, and probably considerably more in Australia, since the oil and gas sector is relatively less important in that country.

Despite the obvious differences in economic dependence on the mineral sector, there is general uniformity in the contribution of the sector to employment (see table 4.2 and figure 4.2). It provided about 1 percent of all jobs in 1985 in most of the countries studied, except in Finland, France and Sweden where the figure was less. For most of the countries, including Canada, employment in the sector declined throughout the first half of this decade (the exceptions were Australia and Finland.) The decline in Canada reflects the effects of the economic recession and poor mineral prices, and the resulting restructuring and rationalization. These factors also played a part in the European countries and the United States, but an important element in these countries has also been the winding down of the industry as economic reserves have been depleted.

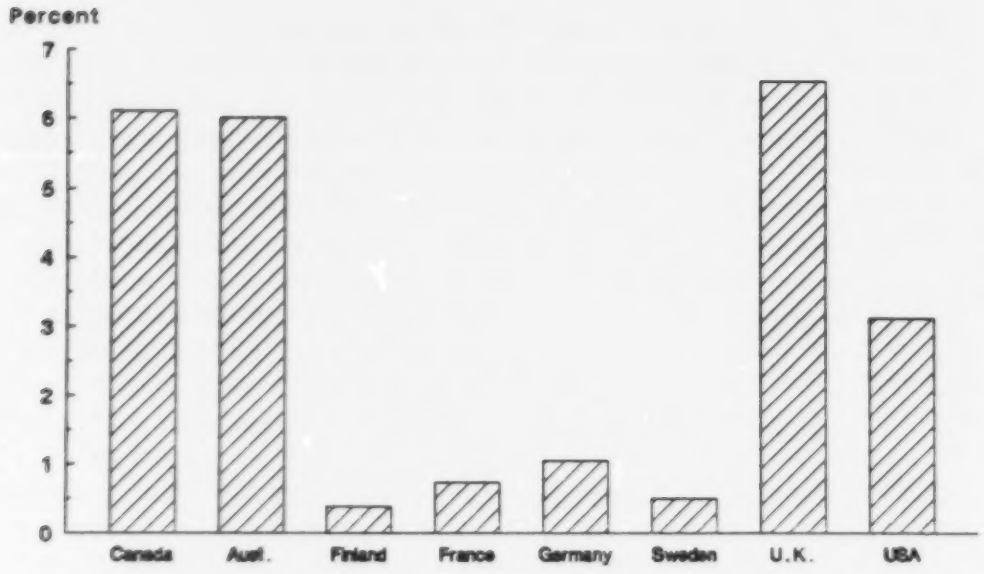

Figure 4.1 Mineral Industry GDP as a Percent of Total GDP, 1985

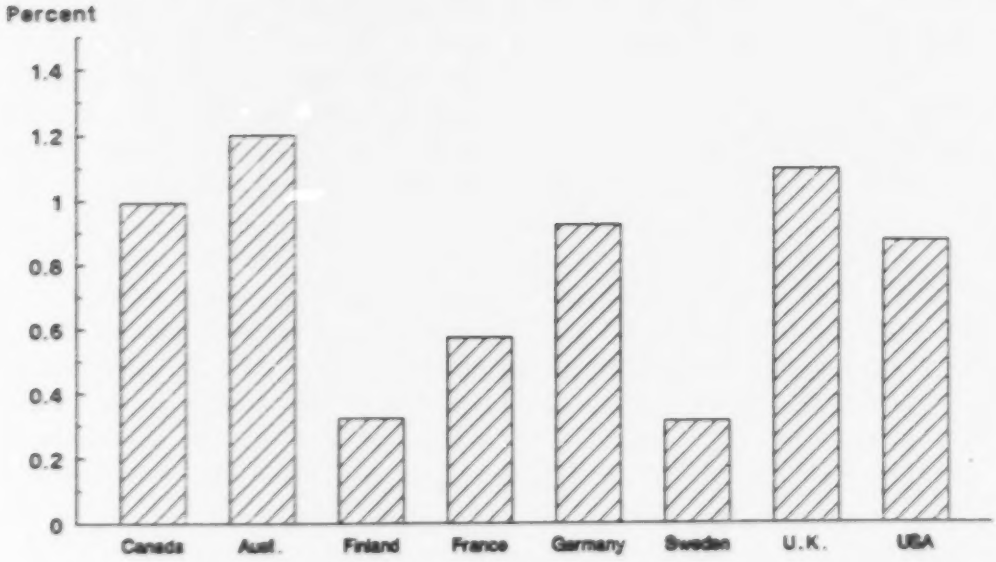

Figure 4.2 Mineral Industry Employment as a Percent of Total Employment, 1985

IMPORT/EXPORT DEPENDENCY

Foreign trade plays a very prominent role in the economic life of all of the countries considered here, with the exception of the United States and, to a lesser extent, Australia. Mineral exports, mainly in unprocessed form, constitute a significant proportion of Canada's total commodity exports. Since domestic production far exceeds domestic requirements, Canada will continue to need access to export markets for its minerals. The countries that are Canada's traditional markets buy Canadian ores and concentrates as feedstock for their own metallurgical operations, in some cases to replace their own depleted resources, and do not offer much prospect for increased demand for refined metals, at least until their current generation of processing facilities closes down or requires replacement. Some newer markets, in the Pacific rim for example, are leapfrogging directly into processing operations, utilizing the newest state-of-the-art technologies. It seems likely that Canada will continue to export much of its mineral output in unprocessed form, particularly in the case of base metals, for the medium term at least. Continued access to world markets for Canadian mineral commodities will depend in large part on cost-competitiveness, and therefore on technological leadership in exploration and production.

Only Australia shares Canada's heavy reliance on export markets for its mineral products and, like Canada, produces a broad range of energy, metallic and nonmetallic minerals in excess of domestic requirements. It is heavily export-dependent in coal, gold, diamonds, alumina and iron ore. More than one-quarter of its exports are accounted for by minerals, a much higher proportion than any other country in this study. Total exports are relatively less important in Australia than in Canada so that, overall, mineral exports in both countries represent about 4 percent of GDP (see figure 4.3).

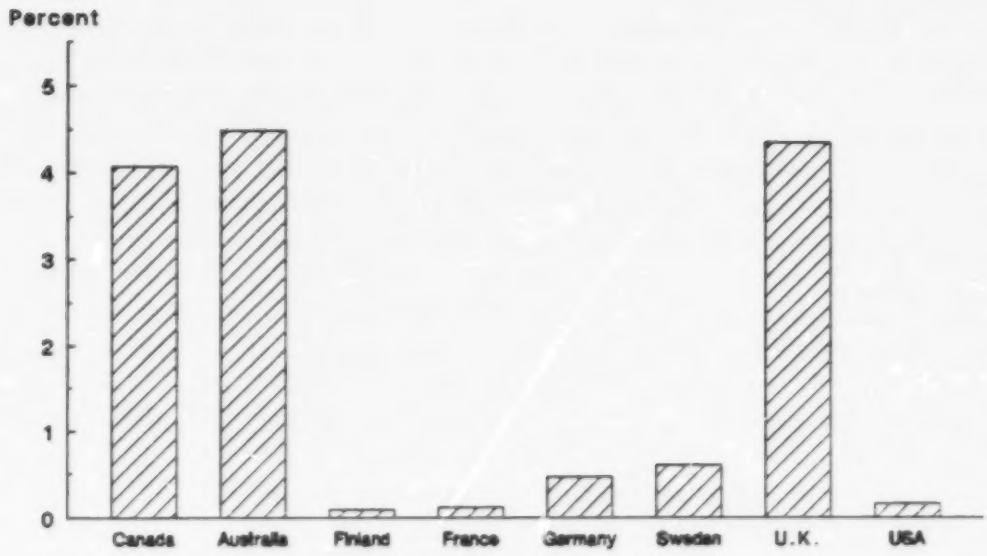

Figure 4.3 Importance of Mineral Exports, 1985
(Mineral Exports as Percent of Total GDP)

All of the other countries studied here are heavily dependent upon imports for their energy needs with the exception, of course, of the United Kingdom. Most of the European countries as well as the United States are also import dependent for metallic ores and concentrates. The exception is Sweden, which is export dependent for iron ore, lead and zinc production.

There are varying degrees of dependence upon imports of industrial minerals. In general, industrial minerals are much more important in domestic markets than in foreign trade.

CONCLUSION

The patterns of the economic impact of the mining and crude petroleum and natural gas sectors in the countries studied are clearly defined. In the 1980s Canada and Australia have seen readjustments that have put their industries in reasonable condition to maintain competitive position and expand reserves over the medium to long term in many mineral commodities. Both will continue to export a significant proportion of metallic ores and concentrates and other crude minerals.

The remaining six countries in the study are in various stages of decline in the production of metallic minerals, with most facing termination of their metal mining industries by early in the next century. Sweden and Finland have no fossil fuel resources, and the coal resources of the remaining European countries studied are high cost and subsidized. All except the UK are dependent on imported energy minerals, in addition to their dependence on imports of metallic ores and concentrates.

CHAPTER 5. INTERNATIONAL COMPARISONS: POLICIES AND ATTITUDES

This chapter will present a synopsis of overall R&D effort in Canada and in the seven other OECD countries considered, in the context of items 3 and 4 in the framework given in chapter 2, the policies and attitudes which influence R&D levels and trends. The first section will examine the R&D implications of policies and attitudes in Canada, the second section will look at the other countries, and the final section will contain a brief quantitative comparison of national R&D efforts.

R&D IN CANADA

In terms of the socio-political environment affecting the mineral industry in Canada and the effectiveness of the industry's R&D efforts in cost reduction, the most distinctive feature is the very broad range of social and political policies that impose costs or offer incentives. For the mineral industry, these policies include incentives and subsidies aimed at regional economic development and various forms of regulation costs. To the extent that the mandated costs exceed the direct economic benefits of the incentives, they will accentuate the troughs of the economic cycles during the mature phase and hasten the approach of the decline. The costs and benefits to the industry are difficult to measure, and they are even more difficult to measure in terms of social welfare.

The R&D implications for the mineral sector are most conspicuous in the area of environmental protection, which has been the motivation for 25 to 30 percent of the mineral-related R&D expenditures in Canada in recent years, both in industry and in the federal government. Regional development policies and policies related to security of energy supply have also been major factors in triggering federal government R&D expenditures.

In the traditional pattern of allocation of responsibility for R&D funding and performance in developed countries, governments have been the major funders of basic R&D and universities the major performers. Business enterprises have had the major role in applied R&D. This pattern has changed dramatically in recent years, in Canada as in most other industrialized nations. Regional and industrial development policies as well as environmental and health and safety concerns have increased government involvement in primary and secondary industries. Basic research funding has been cut in favour of "strategic" research, long-term applied research, or unabashed short-term applied R&D. NSERC's recent five-year plan notes its focus on support for applied research and technological innovation in universities. NRC has likewise moved to greater emphasis on technology and problem-solving R&D.

The result is that there is no agency left in Canada charged exclusively or even primarily with funding basic R&D. The universities have increasingly become performers of applied and sponsored R&D rather than basic R&D. Little effort has been made to link the university R&D activities with industrial requirements, so the success rate for transfer of technology has been low. However, recent federal and provincial government initiatives such as the Network of Centres of Excellence Program and University Research Chairs are designed in part to improve linkages between industry, universities and governments in collaborative research and increase communication among researchers across the country. These initiatives may help to improve technology transfer. They will not resolve the dilemma caused by the fact that the decline in basicresearch reduces the prospects for major innovative breakthroughs.

A second questionable trend in Canadian R&D policies has been a shift away from the primary resource sectors into advanced technologies and the higher value-added aspects of industrial production. While these areas are of prime economic importance for employment and wealth creation, there is little evidence so far of targeting specific aspects of such broad fields as microbiology, information technology or materials technology to direct R&D into areas where Canada already has a comparative advantage. For example, building on advantages arising from domestic sources of raw materials, including mineral commodities, could be a major research focus. The result of this trend to high-tech is a shift away from R&D in primary resources, where we have an established comparative advantage and a base of technological expertise, into new areas where we are competing with a great many other countries with much better records of success in innovation in the high-value-added area than Canada has demonstrated.

One reason for Canada's poor record in commercialization of innovation may be that Canada is not well-placed on the scale measuring attitudes towards science and technology. While this characteristic is difficult to document, its implications are serious, as can be seen by examining its effects elsewhere: for example, the case of iron and steel and of coal in England. In the 19th century, while much of continental Europe had established strong research programs and technical training programs in many areas of engineering and technology, including steelmaking and mining, England continued to stress classical education. Its steel industry was already in trouble, characterized as being trapped in isolated, fragmented production systems, where "science was not only neglected ... it was scorned. There reigned instead the stultifying authority of customary practice and traditional wisdom," according to

Correlli Barnett.1 Nor did Barnett's "practical man" limit his injuries to the steel industry. The coal industry was equally badly served, and by the end of World War II both the coal and steel industries were in sorry shape in the UK (much worse, for example, than in Germany), along with much of the UK's manufacturing capability.

Like the UK, Canada shares many of the symptoms of the "two cultures" syndrome described in chapter 2. It has very few scientists and engineers in management and operating positions and in government policy roles, and it has its share of "practical men" who prefer tradition to innovation. The resulting constraints to innovation, no matter how pressing the need or how good the R&D, can weaken Canada's competitive position and hasten the approach of decline in the mineral sector.

R&D IN OTHER COUNTRIES

Australia

Australia's science policies are relatively new, and frequent changes in programs and government organization have prevented development of a strong, coordinated and focused central R&D policy. Nevertheless the government does fund and perform a significant amount of R&D. The OECD has concluded that the level of scientific activity in Australia compares favourably with that of leading developed countries. It does, however, have a poor record of innovation, and the contribution of industry to R&D is relatively low.

The "two cultures" perception of science and business, and the concomitant lack of communication and even mistrust which divide the two, do not seem to be as prevalent in Australia as in some other parts of the English-speaking world. For example, there seems to be a positive attitude towards joint endeavors in industry, and between industry, government and other organizations, and less concern over secrecy and protection of proprietary rights arising from joint venture R&D findings than in Canada, notably in metals R&D. On the other hand, industry support for R&D is relatively low.

The Australian government has taken the same path as Canada in shifting R&D support away from the natural resource sectors, and especially from the mineral sector. "Designated growth areas" for R&D emphasis have been specified in Australia; for the most part, they deal with high-technology manufacturing. This seems to imply further reduction in relative support for mining and exploration and greater emphasis on high-value-added activities including physical metallurgy and new materials.

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1. Corelli Barnett, The Audit of War (London: Papermac, 1986), p. 97.

Finland

In Finland the government provides a strong direction and focus for R&D. R&D has been a central concern since World War II, with a ministerial-level Science Policy Council, headed by the Prime Minister, directing policy. The government's guiding role in R&D is a reflection of its belief in the efficiency of central government coordination of industrial activity, and of R&D aimed at supporting national goals.

By the end of the 1970s, applied science and technology rather than basic science were being emphasized in government support programs. In the universities nearly all funding for research is sponsored and technology-oriented rather than for "advancement of science". An emphasis on industrial and technology R&D is essentially a short- to medium-term policy perspective . It is not clear what the implications are of the relative lack of basic research, which is longer-term and may not yield a pay-back until well into the future. Nevertheless, Finland has deliberately adopted the view that it is too small to fund a large basic R&D effort. The country continues to be very effective in technological innovation across a broad range of industries, including specialty steels, machinery, and electronics. There is a high degree of technology transfer which is a result of the substantial integration of R&D activities in government, university and industry research organizations.

France

As in Finland, France's R&D policies are highly centralized and organized. They have also been characterized as being project-oriented and, unlike Finland's, very compartmentalized within scientific disciplines and within sectors. The tendency for R&D activity to be "project oriented" implies a relative bias away from basic research, which is less goal-driven in its overall perspective. The compartmentalization of government, industry and university research organizations and researchers discourages scientific communication and technology transfer between the sectors (not to mention collection of R&D statistics). Note that in France this lack of communication is not symptomatic of the two-cultures attitude; the separation is within the scientific and research community itself, rather than between the scientific community on one hand and business and government on the other.

French R&D policy is very much integrated with the government's broad industrial and economic policies. In 1981 science and technology became an election issue and in 1982 the Ministry of Industry and Research was

created to promote technological change and encourage a "technical culture". Legislation was introduced, fixing the growth rate for budgetary R&D expenditures at almost 18 percent per year. New research goals and areas of focus were identified, including major linked programs in electronuclear research, aeronautics and space, and commercialization of advances in various areas including the raw materials industries. One aspect of the national program was a focus on enhancing communication between public and private sector organizations and researchers.

The French mineral industry has been the subject of 3 principal policy thrusts in terms of industrial structure and R&D support. First the government has used a combination of rationalization, nationalization and reorganization in an attempt to counter the effects of depletion, rising costs and import dependency. A second thrust has been the encouragement of offshore (foreign and French territorial) mineral exploration by French companies, in order to ensure a continuing supply of crude minerals. A third thrust, which is related to the second, has been an emphasis on maintaining a high level of expertise in all aspects of mineral production. This has led to the continued life of economically inefficient operations in France in order to provide a means by which French professionals can "keep their hand in" in all facets of primary mineral production.

West Germany

Unlike most countries in this study, and certainly unlike Canada, the most immediately apparent characteristic of West German R&D effort is that it is conducted in an environment of widespread interaction among all sectors of research. There has been a long tradition of support for scientists and scientific development both in society and in government. This attitude has been fostered by the "one culture" mentality in which the scientist, businessman and administrator are perceived to be mutually dependent and sustaining. Careers spanning all three sectors are the rule rather than the exception for senior scientists.

A second area of difference is the strong emphasis on basic R&D. Only Germany and Sweden, among the countries studied, include a major funding component for R&D in the university budgetary funding. This funding is by definition unsponsored, and available for basic R&D at the discretion of university research directors.

A third area of difference is the extensive use of cooperative research institutions. R&D activity is undertaken by a wide variety of researchers, and funds are provided from a wide variety of sources.

There are cooperative institutions with good government-industry-university communication, and a particularly large role is played by the mixed government and private sector research organizations.

Security of supply of raw materials and of energy has been a continuing consideration in government policies affecting the mineral sector, including science and technology policies. In the 1980s, the R&D focus has shifted somewhat towards applied science and technology, but there remains a strong emphasis on basic R&D. Technology transfer and exchanges between industry and researchers have also received renewed emphasis. Technology transfer has been quite successful due to the high mobility of scientific personnel between various research sectors, the proliferation of programs designed to encourage industrial research, and the "one culture" mentality in which engineers and scientists command considerable respect and play important policy formulation and operating roles in industry and in government.

Sweden

The organization of R&D in Sweden can be characterized as decentralized, sectorized and pluralistic. For example, there is no central controlling R&D ministry. Whereas in France this appears to have caused compartmentalization and lack of communication between R&D sectors, in Sweden an integrated but pluralistic decision process has arisen. A wide variety of groups have an influence on R&D policy and funding directions. The government provides active leadership in target identification.

The cooperative and consensus approach to R&D is expressed in the degree to which universities and industry play a role in the national R&D effort; both play a larger role than in most other countries. As noted, universities receive a substantial component of R&D funding in their operating budgets which is available for basic research.

The 1980s have been characterized by a legislative effort to coordinate R&D and provide a broad focus on both basic and applied research in designated sectors. Government R&D support for industry and cooperative R&D organizations has stressed technological innovation. Although a number of specific industrial sectors have been targeted for R&D by government, the mineral sector is not one of them. Nevertheless, a number of interesting R&D joint ventures are underway in the geosciences, mining technology, and mineral processing.

United Kingdom

R&D effort in the United Kingdom appears to be very fragmented, with no strong government leadership in policy. There have been recent attempts to coordinate R&D, at least in the public sector, but it was only in 1982 that the government decided to introduce annual reviews of departmental research programs and budgets. Although the UK, like France, West Germany and other countries, has set up some government research organizations, in the UK the universities remain the focus of Britain's basic research activity. However, there has been a reduction in support for universities as a whole; funding has fallen in real terms, and significant numbers of researchers have left the country. There has been a general move towards rationalization of education and research facilities. Earth sciences have already been targeted for reductions in university programs and funding, and mining is expecting similar treatment.

Applied R&D in the UK is receiving less support from government than in previous years, and industry has not yet picked up the slack. There is a feeling that university links with the private sector are not encouraged. Most of the university funding and staff cuts appear to be aimed at applied schools and programs, while the traditional and well known basic-research-oriented universities have suffered much less. There is little evidence of a strong connection between universities and industry, and there are few joint research establishments.

Among the socio-economic burdens facing the mineral industry in the UK, one that is particularly discouraging to investment in the industry, particularly to exploration, is the very complicated system of ownership and inheritance of mineral rights. The "two cultures" syndrome discussed previously continues to contribute to problems in R&D, technological innovation, and the competitiveness of British industry.

United States

The United States places a strong emphasis on defence R&D, as do France and the United Kingdom. In the 1970s the share of defence R&D in total R&D fell, but under the Reagan administration the trend was reversed. In general, the emphasis in the United States is on development rather than basic or even applied R&D; this may be in part a reflection of the interest in defence.

The United States government perceives its primary responsibility in R&D to be the support of long-term research, which industry is less likely to undertake, and the support of R&D in areas such as defence and environmental regulation in which society as a whole has a stake. The government believes that, with respect to industrial R&D, government's

role is to provide a climate conducive to business R&D initiatives, and that a free-market environment and the collective judgement of economic agents will ensure an appropriate R&D effort.

The "two cultures" phenomenon has been identified as a negative factor in the U.S. innovation effort and in links between its R&D and technology. In spite of U.S. preeminence in R&D and its strong market for high-technology goods, it is argued that this problem has contributed to a wide range of failures in its industrial sector, including falling behind its competitors in productivity, quality of products, and technology trade balance.[2] Competitors such as West Germany and Japan, where science and technology are better integrated into society, are quicker to commercialize and market technological breakthroughs, and faster to adapt to changing supply and demand pressures.

COMPARISONS OF NATIONAL R&D EFFORTS

Up to this point, this chapter has for the most part been qualitative, providing a flavor of what influences R&D and how the roles of government, industry, universities and other organizations vary among countries. This section will provide a brief quantitative and aggregate summary of R&D expenditures. A number of important caveats must be kept in mind when reading this section.[3] First, any international statistical comparison is bound to be affected by problems of consistency. As noted in the first chapter, R&D statistics suffer from incomparability in terms of quality and definition, even at the aggregate level. A second and ultimately much more important consideration is the issue of the reliance on a few simple stand-alone statistics of R&D intensity to capture an understanding of something so complex as R&D activity.

The goal of comparing R&D indicators is to determine how well Canada is doing in relation to other countries in terms of maintaining or increasing R&D effort and focus, with the ultimate goal of comparing potential competitiveness, economic growth, and ability to capture new markets. However, the links between R&D and productivity and economic strength are difficult to evaluate. These statistics should, however, give some indication of where Canada stands. They also give some important insights into who funds R&D and who performs it.

A third important consideration is the comparability of R&D intensity measures, beyond any issue of the consistency of their derivation. Comparisons on an aggregate, nation-wide level do not take into account

2. Lester Thurow, "A Weakness in Process Technology", Science, 18 December, 1987.
3. A good analysis of comparisons of R&D data is given in K.S. Palda and B. Pazderka, Approaches to an International Comparison of Canada's R&D Expenditures (Ottawa: Economic Council of Canada, 1982).

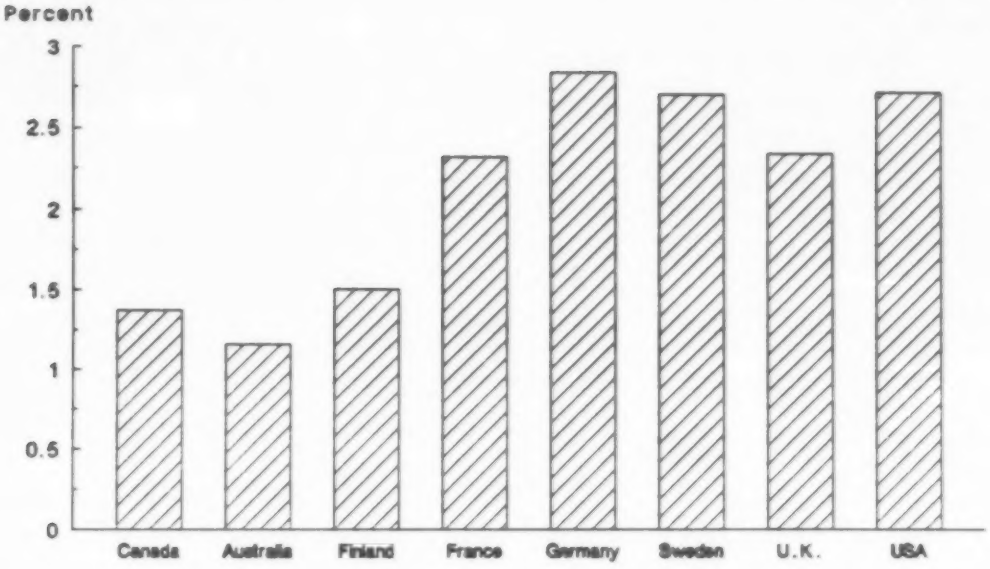

Figure 5.1 National R&D Effort, 1985
(GERD as a % of GDP/GNP)

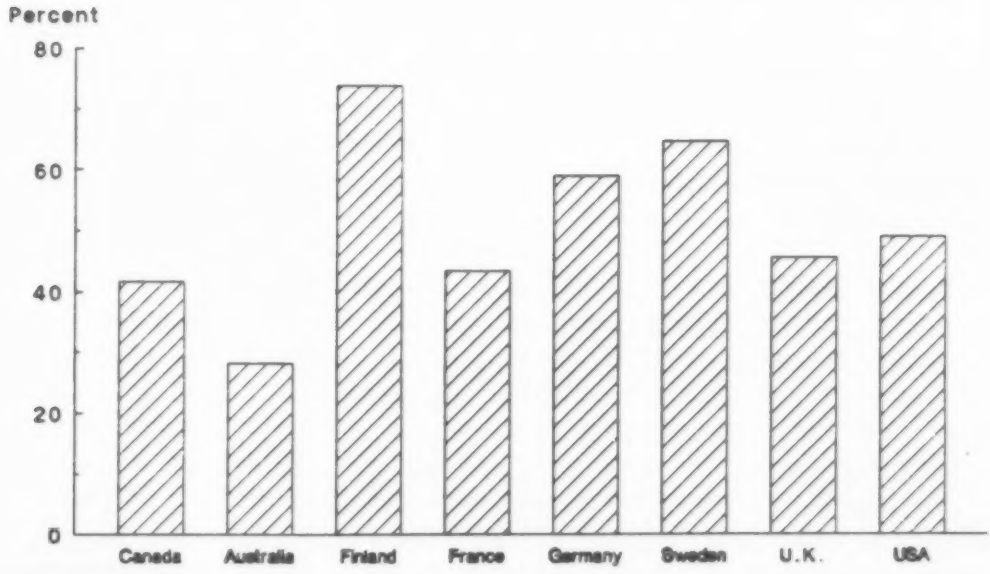

Figure 5.2 Business R&D Effort, 1985
(BERD as a % of GERD)

basic structural differences between countries, such as the sectoral composition of GDP and the importance of defence-related R&D. Different industrial structures and different degrees of import or export dependency imply quite different R&D needs. For example, a relatively small and domestically oriented manufacturing sector, as in Canada, implies that business R&D expenditures will be relatively lower than in countries with larger manufacturing and high-technology sectors, for structural reasons.[4]

A final point to keep in mind is that measures of R&D expenditure intensity are only one indicator of the R&D effort. The statistics must be interpreted in the context of a country's socio-political environment, its attitudes, and other factors that temper the effectiveness of its R&D efforts and its links to innovation and commercialization.

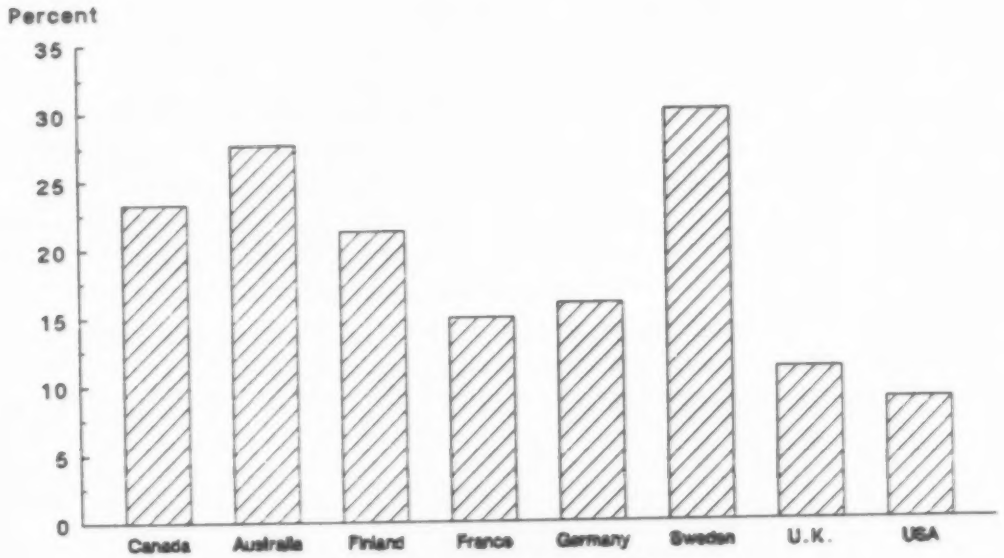

Figure 5.3 Performance of R&D by Institutions of Higher Education, 1985 (Higher Education R&D Expenditures as a Percent of GERD)

(Finland, Germany - 1983, France - 1984)

4. Statistics Canada, Science and Technology Indicators, (Ottawa: 1987), p. 64.

Table 5.1 presents some summary statistics of national R&D efforts. figures 5.1, 5.2 and 5.3 provide graphical representations of some of these data. It is clear that Canada and Australia, the two most heavily resource-based countries, spend much less on R&D than do most of the European countries and the United States. However, France, the United Kingdom and the United States have a large R&D effort in defence. When only non-defence R&D expenditures are considered, these countries' overall R&D intensity ratios fall significantly, although they remain well above the GERD-to-GDP ratio for Canada.5

In terms of business contribution to R&D effort, Canada appears to be roughly in the middle of the countries studied. In 1985, Canadian industry provided about 42 percent of all R&D funds, roughly in line with the proportion in France and the United Kingdom. In Sweden, West Germany and Finland, countries in which there is a fairly high degree of cooperation between sectors, the contribution of business was higher. Industry contributed relatively little in Australia, leaving the government as the key funder of R&D.

In most countries, higher education organizations perform a fairly large proportion of total R&D. The exceptions are the United Kingdom and the United States. In the United States, industry performs a much greater share of GERD than it funds, with the help of government contributions, leaving relatively little funding for R&D performed by universities.6 The relative lack of university R&D in the United Kingdom is perhaps indicative of two aspects of its R&D environment noted in the previous section: first, government funding for university research has not been stressed, and second, there has been little encouragement of industry-university interaction.

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5. Ibid, pp. 151-152.
6. United States National Science Board, Science Indicators: The 1985 Report, (Washington: 1985), p. 33.

Table 5.1 Total National R&D Effort: 1985 (value in 1985 US$ million or percent); or for 1980-1985 (in the case of percent change*)

	Canada	Australia	Finland	France	West Germany	Sweden	United Kingdom	United States
GERD								
Total value	4,782	2,118	678	11,853	17,745	2,705	10,607	107,436
% of GDP/GNP	1.37	1.16	1.50	2.32	2.84	2.70	2.34	2.72
% change	37.9	18.8[b]	23.8[c]	34.9	3.2[d]	na	7.5[c]	31.9
Non-defence								
% of GDP/GNP	1.33[f]	0.98	1.47	1.77[f]	2.72[f]	2.05	1.66[f]	1.89
BERD[g]								
% of GERD	41.7	28.1	73.8	43.4	58.9	64.6[e]	45.6	49.0
% of GDP/GNP	.57	.33	.92	1.01	1.67	1.65[e]	1.07	1.33
% change	45.6	71.3[b]	61.6[c]	34.2	4.9[d]	6.1[e]	na	30.7
Higher Education R&D Performance								
% of GERD	23.3	27.7	21.2[a]	14.9[h]	15.9[a]	30.1[e]	11.1	8.8
% of GDP/GNP	.32	.32	.49[a]	.33[h]	.41[a]	.80[e]	.26	.24

Source: Background Study for each country; Statistics Canada, Science and Technology Indicators, 1987; OECD, Reviews of National Science and Technology Policy, Sweden and Finland, 1987, Australia, 1986; Australian Bureau of Statistics, Research and Experimental Development All-Sector Summary, 1984/85; UK Cabinet Office, Annual Review of Government Funded R&D, 1987; and United States National Science Board, Science Indicators, the 1985 Report.

* Percent growth between 1980 and 1985 based on real domestic currency rates.

na Not available.

a 1983.
b 1981/82-1984/85.
c 1981-1985.
d 1980 value taken as average of 1979 and 1981.
e Natural sciences and engineering only; social sciences and humanities R&D represent about 0.1% of GERD.
f Figures for Canada, France, West Germany and the UK estimated for 1985 based on 1983 non-defence GERD.
g BERD here is R&D funding by business not R&D performed by business.
h 1984.

CHAPTER 6. INTERNATIONAL COMPARISONS: EARTH SCIENCES R&D, GEOSCIENCE AND EXPLORATION

CANADA

In spite of a promising future for its mining industry, and good prospects for the petroleum sector if price arrangements permit, Canada seems to be following a pattern of expenditure in government geoscience activities and earth science R&D that is more appropriate to a country facing the demise of its mining and petroleum sectors. Chapter 3 provided evidence that the A-base or long-term funding of the Geological Survey of Canada and most of the provincial geological survey organizations is declining in real terms. Following the expiry of the MDA agreements in the early 1990s it is unlikely that they will be replaced by any programs with equivalent levels of support. Federal support for energy R&D and incentives for mineral exploration activities seem far more closely tied to commodity prices than to maintaining a long-term security of supply or to considerations of economic viability. NSERC earth science support for individual researchers in universities has not kept pace with overall growth of committee grants. However, federal support for several major earth science projects, the Ocean Drilling Program and Lithoprobe, will start to have a positive effect in the near future.

In the universities, earth science and geology departments are facing the problems of aging of the faculty (a higher proportion of full professors); aging equipment and facilities; and increasing costs of maintenance, replacement and new acquisitions. Although earth science and geology undergraduate enrollment has little direct relation to mineral industry opportunities, there is reason for concern about the sharp drop in first year enrollment over the last few years. Graduate enrollment has grown, but is a smaller proportion of total graduate enrollment than in most of the countries studied.

In terms of industry participation, it is almost impossible to make generalizations because so little data are available. Intuitively, it appears that mining companies do almost no earth-science or exploration-related research in Canada. The Canadian petroleum industry's expenditures are so closely tied to oil prices that the resulting volatility of R&D support may be counterproductive. Companies engaged in drilling and other exploration services do almost no R&D, according to the results of a CRS survey. The major exception, of course, is a small group of geophysical and other exploration-related instrumentation firms, some of whom reported R&D expenditures on the order of 12 percent of revenues.

INTERNATIONAL COMPARISON

Table 6.1 provides a summary of some of the statistical data on earth-science R&D and related activities for comparative purposes. The data unfortunately are too general and too aggregated (and in some cases simply not available) to provide much of a basis for comparison. In looking at geological survey expenditures, for example, it would be much more informative to be able to divide the total expenditures into categories such as budgetary, contracts, and total; domestic and foreign; geoscience and exploration; mineral-related, land-use, and water resources. Unfortunately, these sorts of distinctions are available only in fragmentary or anecdotal form, and are described where possible in the background studies.

Some of the geological surveys are clearly facing declining funds, particularly in Sweden, the USA and the UK. In Germany, BRG funds have been diverted from mineral-related activities to "big-science" projects, and in Finland the value of the mineral-related activities of the geological survey is being questioned. France's BRGM has long concentrated its activities in other countries, and has experienced cuts as well.

In earth-science R&D support by governments, table 6.1 suggests that Canada is at about the same level, in terms of proportion of value of mineral production, as the UK and Germany, and behind the USA. Australia shows a slightly higher rate of growth in R&D support.

Published data sources are not available for industry R&D comparisons in earth sciences. It does appear, however, that R&D and innovation in instrumentation and techniques are most successful where there are links between researchers in universities, mining companies and equipment companies, as in Sweden and Finland, or between equipment companies and exploration firms. In Canada, a strong group of geophysical instrumentation companies grew out of the University of Toronto, in association with mining companies which were mainly U.S.-based or U.K.-based rather than Canadian.

A common factor among the geology and earth science university programs in most of the countries studied is a concern that there are too many departments teaching in the field, often with too many areas of specialization. Rationalization is under way in the UK, and under consideration in France, Finland and Australia, among others. A second common concern is the extremely high cost of the type of equipment needed to stay in the forefront of some areas of earth science research, and the inadequacy of funding programs to provide such equipment.

Table 6.1 Indicators of Earth-Science-Related R&D Activities, 1985 (value in 1985 US$ or percent) or 1980-1985 (% change*)

	Canada	Australia	Finland	France	West Germany	Sweden	United Kingdom	United States
Government Geological Survey Expenditures**								
% change	7.9[a]	10.0[a]	4.9	17.7[b]	4.5	-3.8[a]	-15.0[b]	-2.9
Per sq. km	4	3	36	10	227	8	40	21
% of mineral production	.3	1.8[k]	3.3	.1	.4	na	.1	.1
% of mineral GDP	.6	3.3[k]	5.9	.2[c]	.9	.7	.1	.2
Government Earth Science R&D Expenditures**								
% change	7.6[a]	8.4[a]	na	na	5.2	na	4.1	na
% of mineral production	.2	.4[d]	na	2.2[c]	.2	na	.2	.3
% of mineral GDP	.3	.8[c]	na	4.0[c]	.4	na	.2	.4
Industry Earth Science R&D Expenditures	na	na	na	na	na	na	na	na
Exploration Expenditures								
Mining								
% change	-3.8	-11.4[a]	-2.5	na	na	-3.8	9.2	-16.1
% of production	3.2	3.7[d]	4.7	na	na	5.1[e]	.1	.4
Per sq. km.	36	41	53	na	na	58	10	20
Oil and Gas								
% change	-1.8	-6.8[a]	n/a	na	na	n/a	23.8	17.1[m]
% of production	19.6	27.3[c]	n/a	na	na	n/a	6.5	30.2[c]
Per sq. km.	420	73	n/a	na	na	n/a	7,704	4,272[c]
University Performed Earth Science R&D								
% change	6.0[l]	-3.5[j]	na	na	.2[b]	na	-3.1[a]	.8
% of total	2.4[f]	5.0[c]	na	na	0.9	1.2	na	2.7

Table 6.1 Indicators of Earth-Science-Related R&D Activities, 1985 (value in 1985 US$ or percent) or 1980-1985 (% change*) (continued)

	Canada	Australia	Finland	France	West Germany	Sweden	United Kingdom	United States
Earth Science Degrees Granted								
Undergraduate								
% change	na	8.6	3.9	na	10.0	19.4	16.9[b]	4.6[g]
% of total	.9[h]	1.8[c]	.7	na	1.2[c]	.3[c]	1.7	.8[c]
Graduate								
% change	7.9[i]	na	na	na	19.5	19.6[a]	4.5[b]	-5.5[g]
% of total	1.6[i]	na	na	na	1.7[c]	5.6	2.2	.7[c]

Source: Background Study for each country.

* Average of annual changes based on real domestic currency values.

** There is some double counting between government geological survey data and government R&D data. Geological survey data do not include exploration activities. For Finland, France and Germany the figures for geological survey expenditures per square kilometer are not very meaningful because they include a large component of offshore foreign expenditures but use only domestic land area. For the other countries the data are for onshore domestic survey expenditures per onshore square kilometer. For Germany, $90 federal plus $136 lander are the geological survey expenditures reported. They likely apply to many uses in addition to geoscience data collection. The data for percent change and percent of production use total geological survey expenditures.

na Not available. n/a Not applicable.

[a] 1982 - 1985.
[b] 1981 - 1985.
[c] 1984.
[d] 1983.
[e] Exploration expenditures as a percent of mineral sector GDP.
[f] Earth science R&D in geology and geography departments as % of total sponsored research income.
[g] Based on data for 1982 to 1984.
[h] Enrollment, majors only (2nd to 4th years).
[i] Enrollment.
[j] Based on data for 1978, 1981 and 1984.
[k] Author's estimate.
[l] NSERC support of university earth science research.
[m] 1980 - 1984.

In summary, Canada seems to be following the pattern of decline prevalent in countries that are in the process of winding down their mining sectors. This includes reductions in funds for geoscience data collection and R&D, and a shift away from R&D funding in the primary resource areas. In view of Canada's promising mineral potential, it would seem to make good economic sense at this time to turn away from the present pattern, and strengthen rather than weaken Canada's R&D and technological capabilities in earth sciences and in exploration-related activities.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The purpose of this investigation has been to compare R&D funding trends in the earth sciences in Canada with those in a group of other countries which were selected because they have a tradition of expertise in the earth sciences and because of data availability. Logically, the study's conclusions might be expected to answer the simple question: **How do Canada's R&D efforts in the earth sciences compare with those of the other countries in the study?** Unfortunately, the assembled data do not lend themselves to a simple answer. The data, both from published sources and from original sources are fragmented and incomplete, and are frequently unreliable and not comparable.

Ratios comparing R&D to GDP, for example, show differences in the range of a few tenths of a percent which may seem inconsequential but which in fact can be quite significant. Percent change in various R&D categories is frequently large, but in some cases seem to represent trends that defy reality. Differences over time and between countries may in fact be real, or may reflect differences in definitions, changes in data collection procedures, or other relatively irrelevant intervening factors. The R&D data, in other words, often do not give reliable indications of R&D intensity or trends for comparative purposes. Furthermore, they are not sufficiently complete, comparable, or reliable in their raw form to lend themselves to more rigorous economic analysis to search out hidden implications.

The usefulness of the study arises from a different question, one that is constructive, and can and must be answered if our mineral endowment is to be utilized effectively: **How should Canada's earth science R&D efforts be planned and evaluated?** There is much to be learned from the international comparisons in this study that can help to answer this question. The framework for analysis set out in chapter 2 provides a basis for identifying R&D needs in Canada, and the quantitative and qualitative information in the background studies helps to identify the opportunities and constraints that must be recognized if the R&D needs are to be met. Meeting the R&D needs, however, is not sufficient in itself. The analysis also offers insights into the successful transition from R&D to innovation and commercialization, to support a competitive position.

STAGE IN THE LIFE CYCLE

Canada is in the mature phase of the mineral industry life cycle with excellent long-term potential for a broad range of crude metallic and nonmetallic minerals and a strong background of exploration ability. In contrast, most of the countries in this study are facing the depletion of their metallic mineral deposits and are reducing exploration activity as their mineral industry starts to wind down. Nevertheless, these countries represent a significant proportion of the existing earth science R&D and exploration and geoscientific expertise and of the educational tradition in the earth sciences.

At the same time, a number of newly developing countries (which were not part of this study) are or are in the process of becoming strong competitors as producers of crude minerals. Many are receiving geoscientific assistance from Canadian government agencies, consulting firms, and mining companies. In order to compete with these countries, and continue to realize the wealth inherent in its own mineral endowment, Canada must remain among the low-cost producers and seek to ensure that economic mineral reserves continue to be identified in Canada.

Recommendation: To remain competitive, Canada must maintain and enhance its commitment to earth science R&D and to its geological survey organizations.

Such a policy direction must involve several avenues of emphasis including basic geoscience data collection and development of theories and techniques for identification of mineral occurences and deposits at depty. All R&D funding and performing sectors (government, industry, and universities) must play a role. At both the federal and provincial levels, governments must reverse the underlying decline in interest in geological surveys as reflected in the A-base of the GSC and the provincial surveys. This is demaging to long-term programs, and leads to an aging and less effective research organization.

Recommendation: The GSC and the provincial geological survey organizations should rely less on add-on funding, and maintain or increase their long-term funding commitments. The GSC is among the world's best such organizations and, with the provincial surveys, should be recognized as an integral component of the effort to remain competitive in mineral exploration, and of the effort to maintain the highest standards in earth science R&D and education in Canada.

In Canada there appears to be an attitude that it is the role of government to fund earth science R&D; in addition, governments and universities are the major performers. Industry plays little part and has few links with either of the performing sectors. More industry interest and participation in earth science R&D is needed. This can be fostered by developing a cooperation between industry, government and universities. Countries where there is a high degree of cooperation in R&D also tend to be characterized by a higher industry contribution towards R&D. To cite a Canadian example of the benefits, R&D and innovation in geophysical instrumentation and techniques profited greatly from collaboration between mining companies and the University of Toronto in the decade or two following World War II. The links between universities and mining and equipment companies in Sweden and Finland have been an important component of the success in developing mining equipment in those countries. Industry support should include funding, demonstration opportunities, and hands-on participation by industry end-use experts in the R&D.

Recommendaton: Industry should develop an interest in earth science R&D, and establish closer cooperative links with university and government earth science research programs.

IMPORT-EXPORT DEPENDENCY

Australia is the only country included in this study with a greater dependence than Canada on export markets for its domestic production of crude metallic and energy minerals. All the other countries are increasingly dependent on imported mineral commodities, and increasingly focusing their R&D efforts on conservation of materials, substitution away from imports, and other downstream manufacturing areas. They are reducing their domestic exploration activities as the likelihood of economically useful discoveries declines. Both Canada and Australia are also turning away from natural resources and towards manufacturing and high-technology R&D activities. However, the likelihood of long-term dependence on export markets for crude minerals reinforces the recommendation that Canada should target earth science and exploration R&D and geoscience data collection, in order to maintain competitive position and an inventory of mineral reserves.

ECONOMIC, SOCIAL AND POLITICAL FACTORS

Canada shares with the other countries in this study a complex network of government policies and economic and social pressures that affect the mineral sector in the form of both costs and incentives. Some of these pressures have been instrumental in hastening the decline of the mineral sector in Europe and the United States, and place economic burdens on the sector in Canada and Australia as well. These pressures tend to be less burdensome in some of the newly developing countries, although they may have cost burdens of their own that are in some cases equivalent.

With respect to exploration activities it is crucial that incentives be carefully designed and implemented so as to minimize distortions in the allocation of resources and the resulting economic inefficiencies. At the same time it is important that exploration in both the mining and petroleum industries be buffered somewhat from the volatility induced by balance sheet fluctuations, incentive programs, price movements and other factors that afflict the mineral sector. Exploration requires a long lead-time, and should be based on long-term considerations of security of supply rather than on short-term cash flow considerations.

Recommendation: Governments must continue to ensure that their exploration incentive programs contribute to stability in exploration expenditure levels, with a minimum of economic distortion. For its part, industry must realize that it is in its own interest to consider exploration activity as a long-term investment.

Two important and relatively recent trends which may have a potentially profound effect on the mineral sector are first, the already noted, increasing emphasis on high-technology research at the expense of natural-resource-related research and second, a growing emphasis on applied rather than basic research. Most of the countries in this study, including Canada, are following these trends. While the first trend may be appropriate for some countries and for certain resource sectors it is not suitable for Canada's mineral sector. The second trend, the increasing focus on applied research at the expense of basic research, is short-sighted both in Canada and abroad. A few countries have in fact made a concerted effort to retain a balanced research agenda. Canada must follow suit if it wishes to stay a leader in this area of technology where it now has a comparative advantage. Only basic research leads to shifts to new innovation curves.

Recommendation: R&D performing and funding sectors should recognize the importance of maintaining or increasing their R&D efforts in mineral resource related R&D, including the earth sciences. A better balance of basic R&D in the overall R&D program is needed, since it is basic research which ultimately creates the major innovative breakthroughs in any industry or discipline.

Particularly in engineering, students are encouraged or discouraged from various specialties by the availability (or lack of) summer employment that provides both professional growth and funding for completing their studies. Too often in earth sciences and mining, these jobs vanish in the economic troughs, and then the students are not around when the peaks return.

Recommendation: Industry should make a point of offering useful and challenging opportunities for summer employment to undergraduates, even in the face of short-term cash flow problems.

THE CULTURAL FACTOR

As noted previously, this factor is perhaps the most difficult to measure quantitatively. However, it is clear that Canada attracts relatively few of its own top students into PhD programs. It also places relatively few scientists and engineers in operations and management in industry or in government, and promotes relatively few to the senior executive positions. This failure to hire and promote has many negative effects on R&D policies and effectiveness, not the least of which is that it exacerbates the first problem, that of failure to attract top students, by limiting career opportunities. These failings affect the earth sciences along with all other fields of R&D and innovation.

Although it may not be possible to change the underlying causes or nature of Canada's attitudes towards science and technology, it is possible to change the ways in which R&D efforts are organized and utilized. R&D and innovation efforts must include incentives and bridges to overcome the long-standing separation of scientists from operations and from senior management and policy formulation. Several possible approaches are suggested in the recommendations that follow.

Recommendation: Industry should make greater use of university graduates in science and engineering, at both the undergraduate and graduate levels, in production and operations as well as in research.

This will have a number of positive effects, including transfer of knowledge acquired through research directly to operations, and opening up career opportunities at all levels of operations and management.

Governments have a major role to play in encouraging greater industry participation and greater cooperation in R&D efforts, and in promoting technology transfer. They can also assist in dampening the volatity of the mineral exploration industry and its R&D, through equitable taxation policies and short-term incentive programs.

Recommendation: Government should place more scientists and engineers in operational and in policy-formulation roles.

Recommendation: Government should encourage communication and technology transfer through support of collaborative R&D involving end-users.

Recommendation: Government should help industry to dampen swings in R&D funding that result from volatility in cash flow in the industry.

Universities have a role to play in encouraging cooperation as well, although they have been among the worst offenders in terms of isolation of science and engineering from other disciplines, and vice versa, and isolation of basic research from industrial applications.

APPENDIX A. SUMMARY OBSERVATIONS FROM BACKGROUND STUDIES

Australia*

Economy:

- originally based on resources, overtaken by manufacturing in 1950s;
- little real GDP growth since 1970s;
- exports about 15 percent of GDP, principally wool and other rural (34 percent of exports) and coal (15 percent);
- current account balance negative and growing.

R&D Policies and Funding:

- GERD 1.2 percent of 1985 GDP;
- science policy relatively new (since 1970s);
- frequent studies and reorganizations, no strong policy focus or central leadership;
- strong federal government role in R&D performance (CSIRO) and funding;
- shift in focus from basic resources to value-added sectors.

Geoscience and Exploration:

- government geological survey expenditures grew strongly, 17 percent from 1982 to 1985;
- exploration expenditures down in mining and in oil and gas.

Mining Industry:

- strong in mining, primarily coal and also metallic;
- dependent on export markets for most of crude mineral production;
- private sector is 30 to 50 percent foreign owned;

Education:

- pressures for rationalization and consolidation of earth science education.

Earth Science R&D:

- BMR's funding steady in early 1980s, declining in last two years;
- government R&D in earth sciences down by 26 percent 1981-84.
- joint industry R&D effort in AMIRA.

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* Margot Wojciechowski, "R&D Trends in Earth Sciences in Australia," Background Study to Final Report, Research and Development in the Earth Sciences, prepared for Canadian Geoscience Council by Centre for Resource Studies, Kingston, 1989.

Finland*

Economy:

- GDP growth strong 1975 to 1985, dropping off in 1986;
- based largely on forest products and metal products;
- strongly export-oriented - about 30 percent of GDP;
- import dependent for almost all energy supplies and metallic ores and concentrates.

R&D Policies:

- strong central direction;
- GERD 1.68 percent of 1987 GDP and increasing;
- strong applied focus;
- declining emphasis on primary resources, increased emphasis in manufacturing and technology.

Geoscience and Exploration:

- slow growth in geological survey expenditures, strong emphasis on mineral exploration (about 40 percent of budget);
- mining company exploration expenditures dropping fast;
- offshore (foreign) exploration activity being cut.

Mining Industry:

- exploration increasingly by government, industry cutting back almost to zero;
- mining dominated by two state-owned metal firms and one state-owned industrial mineral firm;
- iron mining close to finished; nonferrous facing depletion;

Education:

- earth sciences - enrollment limits and rationalization;
- mining - diversification into geotechnical and underground construction;

Earth Science R&D:

- R&D declining in exploration and mining;
- increased emphasis on geotechnical for underground constructon.
- strong collaboration between university and industry.

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* Margot Wojciechowski, "R&D Trends in Earth Sciences in Finland," Background Study to Final Report, Research and Development in the Earth Sciences, prepared for Canadian Geoscience Council by Centre for Resource Studies, Kingston, 1989.

France*

Economy:
- since late 1970s, dominated by service sector, with manufacturing second;
- minimal role for mineral sector;
- much of economy and financial sector nationalized;
- moderate export orientation (about 24 percent of GDP);
- import dependent on mineral raw materials;
- emphasis on nuclear energy.

R&D Policies:
- highly centralized, organized, project-oriented, compartmentalized, isolated within sectors;
- GERD about 2.2 percent of GDP (1985);
- government contribution about 60 percent;
- defence 30 percent of R&D;

Geoscience and Exploration:
- geological survey expenditures up 18% from 1980 to 1985;
- exploration mainly outside France.

Mining Industry:
- mainly state-owned, mainly coal;
- metal mining in last stages of decline;
- considerable foreign mineral holdings.

Education:
- strong tradition in mining, less so in earth sciences;
- facing possibility of rationalization, diversification,

Earth Science R&D:
- isolation of basic and applied, university and industry R&D.

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* Margot Wojciechowski, "R&D Trends in Earth Sciences in France," Background Study To Final Report, Research and Development in the Earth Sciences, prepared for Canadian Geoscience Council by Centre for Resource Studies, Kingston, 1989.

Germany*

Economy:
- GDP growth slow in 1980s;
- based on manufacturing;
- very little dependence on basic resource industries;
- strongly export-oriented: about 30 percent of GDP;
- import-dependent for mineral and some energy raw materials;
- emphasis on nuclear energy.

R&D policies:
- strong state and federal government leadership;
- GERD 2.8 percent of GDP;
- strong role for mixed government/private sector research organizations;
- emphasis on university and basic R&D;
- very good government-industry-university communication;
- high proportion of R&D in joint institutions.

Geoscience and Exploration:
- state and federal geological surveys funding increase averaged 1% per year 1980-85;
- exploration subsidies ended;
- mining exploration declining.

Mining Industry:
- largely privately owned;
- metal mining in last stages of decline;
- dominated by coal mining.

Education:
- growth in earth science enrollment.

Earth Science R&D:
- decline in exploration-related R&D;
- increase in "big science" earth science projects (deep drilling and seismic);
- government earth science R&D increased an average of 1 percent per year 1980-85.

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* Margot Wojciechowski, "R&D Trends in Earth Sciences in Germany," Background Study To Final Report, Research and Development in the Earth Sciences, prepared for Canadian Geoscience Council by Centre for Resource Studies, Kingston, 1989.

Sweden*

Economy:
- real GDP growth of about 9 percent from 1980 to 1985, down from mid-1970s rate of increase;
- economy hurt by rising costs in late 1970s and early 1980s, particularly energy and wage costs;
- export dependent (30 percent of GDP), mainly machinery and other metallic manufactured goods;
- import dependent for energy minerals and some metallic ores;
- low unemployment rate.

R&D Policies:
- R&D effort driven by export dependence on high-value-added goods;
- strong basic R&D focus, growing applied support;
- active government leadership in target identification;
- strong emphasis on cooperative R&D;
- leading industry role in R&D funding and performance;
- GERD 2.5 percent of 1985 GDP;
- government geoscience (geological survey) expenditures declining.

Geoscience and Exploration:
- geological survey expenditures dropping;
- proportion of geoscience activities in mineral-related fields falling as well;
- exploration not very active - some in base metals and gold;
- exploration subsidy being wound down.

Mining Industry:
- dominated by iron ore, state-owned;
- nonferrous sector concentrated, privately owned;
- ferrous mining facing depletion within a few decades, nonferrous looking for domestic deposits to continue operations;
- exploration expenditures dropping.

Education:
- strong emphasis on R&D in higher education sector;
- earth science degrees climbing, geotechnical falling.

Earth Science and Mineral Sector R&D:
- good liaison between government, mineral and equipment companies and universities;
- R&D intensity in mining steady, about 1 percent of sales;

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* Margot Wojciechowski, "R&D Trends in Earth Sciences in Sweden," Background Study to Final Report, Research and Development in the Earth Sciences, prepared for Canadian Geoscience Council by Centre for Resource Studies, Kingston, 1989.

United Kingdom*

Economy:
- GDP growth in 1980s due mainly to oil and gas;
- high unemployment - 11.5 percent in 1985;
- resource sector very small, service sector almost double manufacturing.

R&D Policies:
- very fragmented, no strong government policy leadership;
- defence-dominated;
- government/industry contribution about 40/60;
- performance sector characterized by relative isolation of sectors, institutions;
- government support of civil R&D weakening (both university and industrial).

Geoscience and Exploration:
- geological survey expenditure down 15 percent 1981-85;
- exploration subsidy ended;
- mining exploration activity very small;
- oil and gas exploration dropping, moving onshore.

Mineral Industry:
- mining dominated by government-owned coal production;
- coal need modernization, rationalization;
- metal mining in last stages of decline;
- oil and gas industry strong, but past its peak and facing depletion.

Education:
- undergraduate growth strong (17 percent) and graduate moderate (5 percent) from 1980 to 1985;
- earth science facing severe cuts in rationalization program.

Earth Science R&D:
- little useful data on R&D expenditures;
- very little metal mining R&D;
- coal mining R&D declining, government research centre closed;
- university earth science R&D funding down 3 percent, 1980-85;
- government R&D support for earth science increased less than 1 percent per year, 1980-85.

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* Margot Wojciechowski, "R&D Trends in Earth Sciences in the United Kingdom," Background Study to Final Report, Research and Development in the Earth Sciences, prepared for Canadian Geoscience Council by Centre for Resource Studies, Kingston, 1989.

United States*

Economy:
- real GDP growth erratic in 1980s, down in 1982, up strongly in 1984, up 12.7 percent from 1980 to 1985;
- based on manufacturing;
- resource sectors insignificant;
- not export-oriented, but growing negative trade balance;
- import dependent for most metallic minerals, some petroleum.

R&D policies:
- dominated by defence R&D;
- government/industry contribution about 50/50;
- little overall central leadership;
- strong federal leadership in defence, health and energy.

Geoscience and Exploration:
- real Geological Survey expenditures down 41 percent between 1980 and 1985;
- exploration expenditures down in mining, up in oil and gas as of 1985.

Mineral Industry:
- dominated by oil and gas, almost 80 percent of mineral production and 2.5 percent of GDP in 1985;
- privately owned;
- mining dominated by coal;
- metallic mining sector declining;
- heavy environmental and regulatory costs.

Education:
- many departments, growth in undergraduate degrees, and decrease in graduate degrees granted;
- university R&D support low in earth sciences, relative to proportion of graduate students;
- university R&D declined slightly, 1980-85.

Earth Sciences and Mineral Sector R&D:
- little data on industry earth science R&D available;
- industry R&D has probably fallen.

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* Margot Wojciechowski, "R&D Trends in Earth Sciences in the United States, "Background Study to Final Report, Research and Development in the Earth Sciences, prepared for Canadian Geoscience Council by Centre for Resource Studies, Kingston, 1989.

APPENDIX B. Price Indices and Exchange Rates

Table 1 Implicit GDP/GNP Price Deflators, 1975-1988

Table 2 Exchange Rates, Various Years

Table 3 Comparison of Canadian Price Indices, 1981-1987

Table 1 Implicit GDP/GNP Price Deflators, 1975-1988 (1981 = 100)

	Canada GDP	Australia GDP	West Germany GNP	Sweden GDP	France GDP	United States GNP	United Kingdom GDP	Finland GDP
1975	60.6	56.2	78.7	55.9	55.3	63.1	45.1	56.8
1976	65.8	63.9	81.5	62.6	60.7	67.2	51.7	64.0
1977	69.9	69.8	84.6	69.1	66.4	71.6	58.8	70.5
1978	74.2	74.9	88.2	75.7	73.2	76.9	65.4	75.9
1979	81.6	81.9	91.7	81.7	80.6	83.7	74.9	82.2
1980	90.3	91.4	96.2	91.3	89.8	89.7	89.7	89.8
1981	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1982	108.9	110.9	104.4	108.6	111.7	107.7	107.7	109.1
1983	114.3	120.6	107.8	119.2	122.6	113.2	113.2	118.6
1984	118.4	129.2	109.9	128.3	131.7	117.8	117.8	129.2
1985	122.4	136.9	112.3	137.2	139.3	124.8	124.8	137.0
1986	125.8	147.0	115.8	146.9	145.8	129.8	129.6	143.5
1987	129.2	165.7	118.2	154.5	150.4	125.1	135.4	
1988	132.6[a]							

Source: International Monetary Fund, International Financial Statistics, 1987 and September 1988; Bank of Canada, Review; and United States Department of Commerce, Statistical Abstract of the United States.

[a] First quarter, 1988.

Table 2 Exchange Rates[a] Various Years (Domestic Currency per U.S. Dollar)

	Canada	Australia	West Germany	Sweden	France	United Kingdom	Finland
1975	1.0172	0.7632	2.4603	4.1522	4.2862	0.4501	3.6787
1979	1.1714	0.8945	1.8329	4.2871	4.2544	0.4713	3.8953
1980	1.1692	0.8776	1.8177	4.2296	4.2256	0.4299	3.7301
1981	1.1989	0.8701	2.2600	5.0634	5.4346	0.4931	4.3153
1982	1.2337	0.9829	2.4266	6.2826	6.5721	0.5713	4.8204
1983	1.2324	1.1082	2.5533	7.6671	7.6213	0.6592	5.5701
1984	1.2951	1.1369	2.8459	8.2718	8.7391	0.7483	6.0100
1985	1.3655	1.4269	2.9440	8.6039	8.9852	0.7714	6.1979
1986	1.3895	1.4905	2.1715	7.1236	6.9261	0.6817	5.0695
1987	1.3260	1.4267	1.7974	6.3404	6.0107	0.6102	4.3956

Source: International Monetary Fund, International Financial Statistics, 1988.

[a] Rates are period averages of market exchange rates.

Table 3 Comparison of Canadian Price Indices, 1981 - 1987
(1981 = 100)

	1981	1982	1983	1984	1985	1986	1987
Consumer price index							
CPI total	100	110	117	122	127	132	138
CPI durable goods	100	105	110	113	117	123	127
CPI services	100	113	120	125	130	136	143
Raw materials price index							
Total excluding coal & oil and gas	100	97	99	103	100	104	109
Coal and oil and gas	100	120	129	131	137	87	94
Mineral raw materials price index							
Total	100	113	120	122	126	90	97
Excluding coal & oil and gas	100	93	97	98	95	98	107
Metallic materials							
Copper concentrates	100	88	92	81	87	90	106
Iron ore	100	104	105	110	114	116	111
Lead concentrates	100	71	58	73	57	68	106
Nickel concentrates	100	91	85	93	99	87	97
Other base metals, n.e.s.	100	91	95	105	95	97	104
Precious metals	100	83	99	85	77	88	99
Gold ingots	100	83	98	85	78	91	101
Silver	100	75	111	82	66	60	73
Platinum	100	77	100	88	74	119	139
Radioactive concentrates	100	110	99	95	92	91	89
Zinc concentrates	100	90	96	118	105	102	108
Nonmetal materials							
Asbestos	100	101	111	110	108	108	108
Other nonmetallic materials, n.e.s.	100	111	110	114	116	118	118
Sand and gravel	100	109	109	108	109	112	117
Silica sand	100	111	117	115	118	122	123
Stone	100	113	124	128	134	139	143
building	100	112	123	128	133	137	141
crushed	100	115	128	135	143	151	157
other	100	112	123	128	133	137	141
Sulphur	100	113	99	114	167	179	146
Mineral fuels							
Coal, thermal	100	110	111	119	120	119	120
Oil, crude	100	121	130	132	139	80	89
Natural gas	100	128	134	132	132	129	125

Source: CPI and Raw Materials PI, Bank of Canada Review, September 1988, pp. S128-9; Statistics Canada, 62-011.

n.e.s. Not elsewhere specified.

THE CENTRE FOR RESOURCE STUDIES

The Centre for Resource Studies (CRS) was established in 1973, under the sponsorship of Queen's University, the federal Department of Energy, Mines and Resources, and The Mining Association of Canada, to carry out a program of research and publication on mineral policy issues.

The Centre provides opportunities for multidisciplinary research in resource studies at Canadian universities, furnishes reliable information on matters related to mineral resource policy, and promotes closer liaison between government, industry and other concerned groups. The research program is carried out both at the Centre and by means of contracts with qualified investigators, usually at Canadian universities. Small exploratory studies are also funded, through a system of grants-in-aid of research. CRS Seminars involve representatives from governments, industry, universities, labour, and other interested groups in working sessions on issues of current concern. Through this program of research and seminars, and the resulting publications, the Centre contributes to informed discussions and a better understanding of significant issues.

The Centre is governed by a board of directors which establishes general policy and priorities for research. The board has sixteen members, appointed by Queen's University, The Mining Association of Canada, and the federal government. Guidance on the research program, together with discussion of policy issues and other matters, is provided by the Advisory Council. This body comprises all researchers associated with the Centre, together with members appointed from such groups as governments, industry, labour, and other interests. A Research Advisory Committee aids in the development of projects and the selection of research proposals. The executive director and staff are responsible for the work of the Centre within this framework.

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The Centre welcomes comments on its publications, proposals for research projects or for publication, or enquiries about any aspect of its work. For further information, contact:

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